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THESIS

DUAL-PHASE NOZZLE FLOW

by

Thomas C. Nollie, Jr.

Ocotber 1982

Thesis Advisor: J. F. Sladky

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Dual-Phase Nozzle Flow

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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ABSTRACT

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I. DUAL-PHASE CYCLE

The dual-phase nozzle is a key element in the dual-phase engine concept. This nozzle will be studied in detail, but first a review of the dual-phase cycle will be carried out from information obtained from References 1 and 2.

Reference 1 describes the dual-phase engine. It is a new concept which operates on a mixture of two fluids or two phases of one fluid. This cycle employs a high-torque/low-rpm impulse turbine which eliminates the requirement for speed reduction needed in a conventional steam turbine. This allows for direct drive of a ship's propeller with no gear reduction. This is ideally suited for marine propulsion, reducing weight, noise, and volume.

The dual-phase concept is a modified Rankine cycle with subtle differences of extreme importance. In a normal steam turbine the working fluid enters a turbine through a nozzle where the kinetic energy of the working fluid is converted to a mechanical form. The dual-phase system introduces a second fluid prior to entry into the nozzle. This fluid is of higher vapor pressure than the steam and therefore remains in the liquid state throughout the cycle. Section A will describe this two-component cycle while section B will do the same for a single-component system. The dual-phase

system can be divided into the two groups illustrated in Figure 1. Single-component flow can be further divided into three categories.

A. TWO-COMPONENT

A two-component mixture is one in which the low vapor pressure liquid and a high vapor pressure liquid are of different chemical compounds. Some fluid combinations which have been considered are steam-krytox, steam-caloria, steam-lead, bismuth eutectic, and dow-therminol. A schematic flow diagram and process representation on the T-S diagram are shown in Figures 2 and 3 for the two-phase engine cycle using a "two-component" mixture. The liquid phase is lithium carbonate and vapor phase is steam. To illustrate the overall advantages of the two-phase engine cycle a discussion on the theory of operation will be presented using a two-component mixture and Figures 2 and 3.

The major component of the dual-phase system is the nozzle. A mixer area is located prior to the nozzle inlet. A high vapor pressure liquid is placed in contact with the low vapor pressure liquid in this area. A high pressure vapor liquid mixture is formed. Since the temperature of the liquid is greater than temperature of the water, heat is transferred to the water causing it to vaporize to point 1. Figure 4 illustrates the temperature and state point from the inlet of the mixture area to the nozzle exit. This mixture is

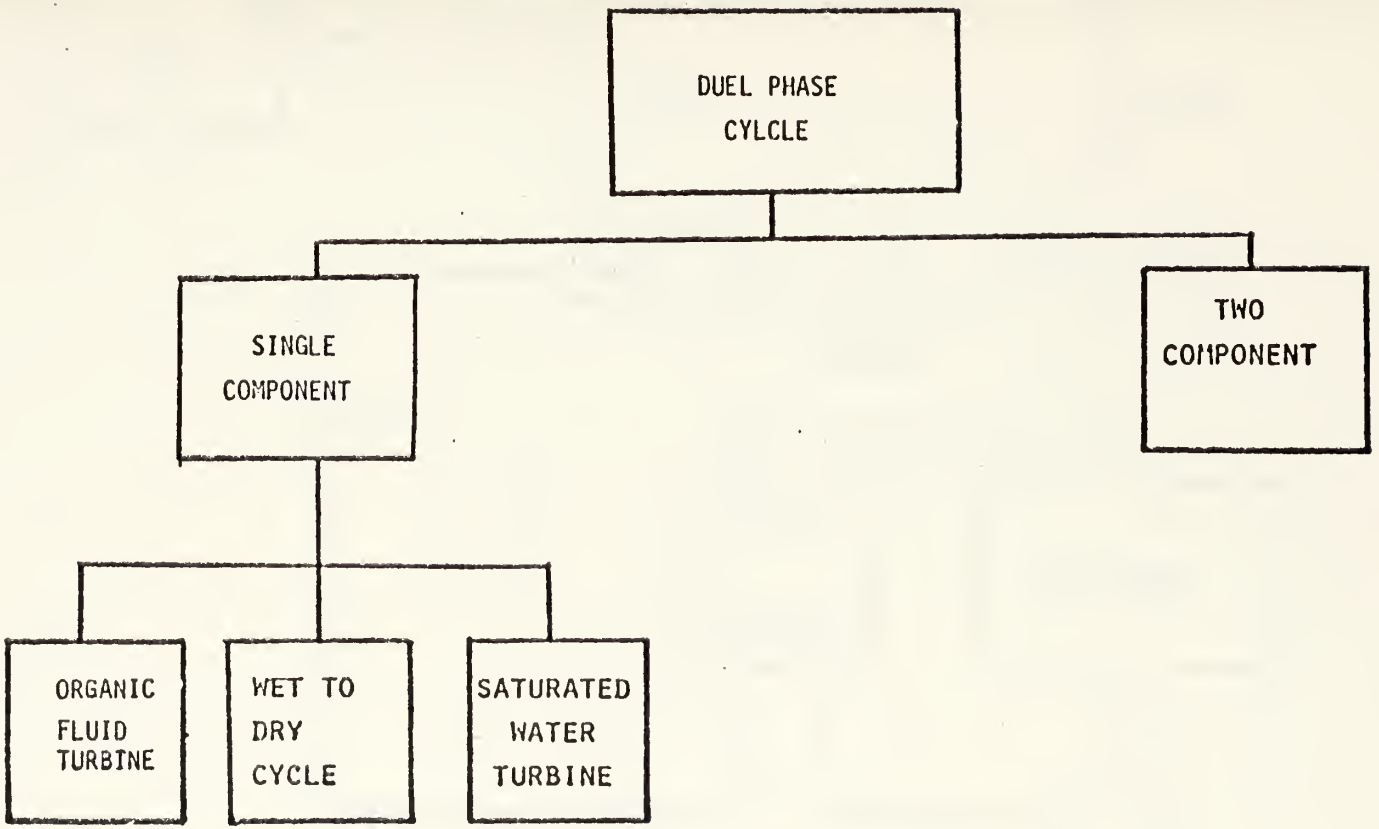


Figure 1. Division of the Dual-Phase Cycle

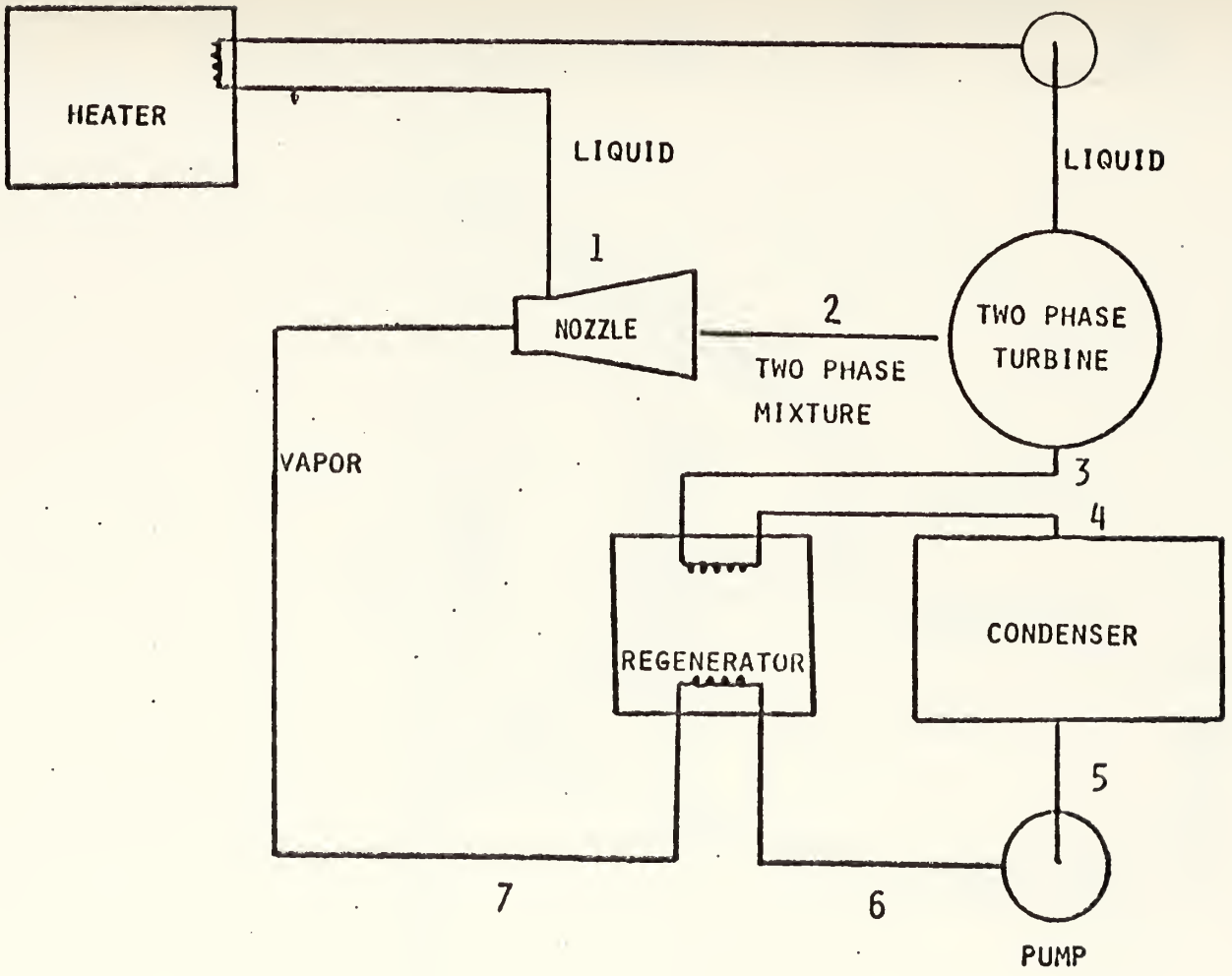


Figure 2. Dual-Phase Two-Component System

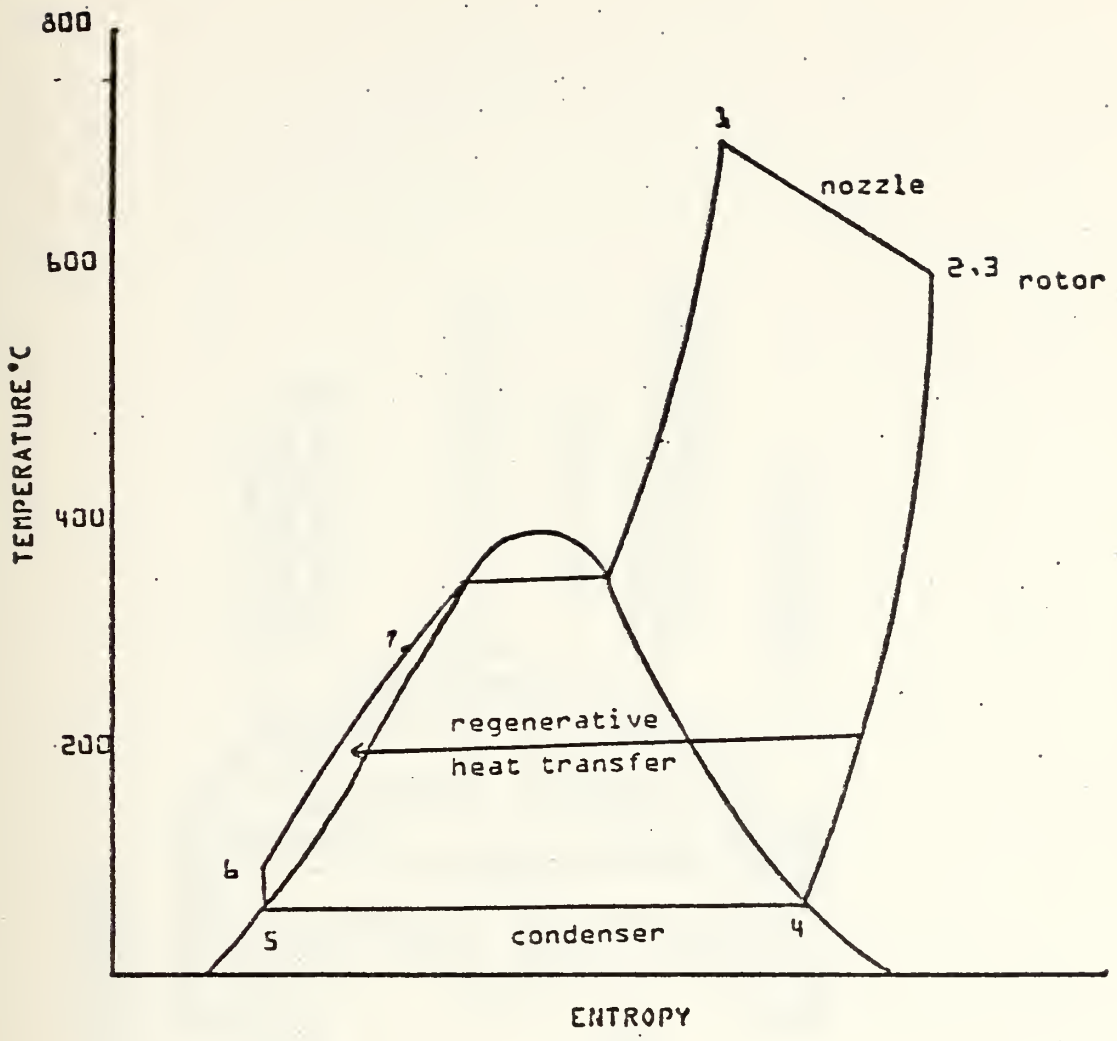


Figure 3. Dual-Phase Two-Component T-S Diagram

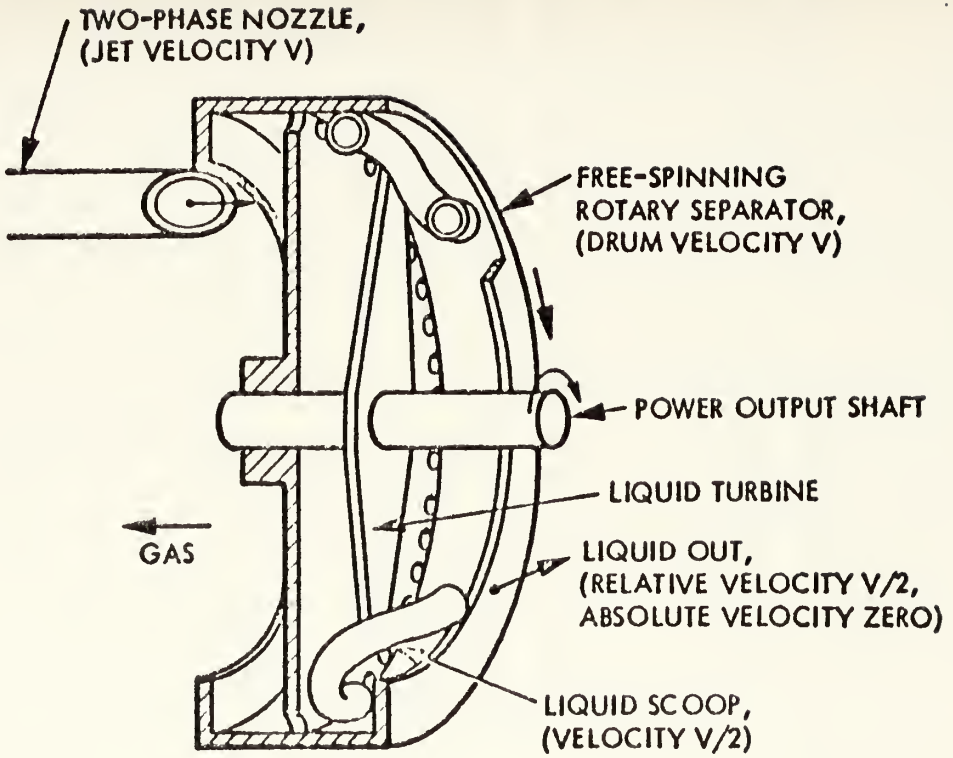
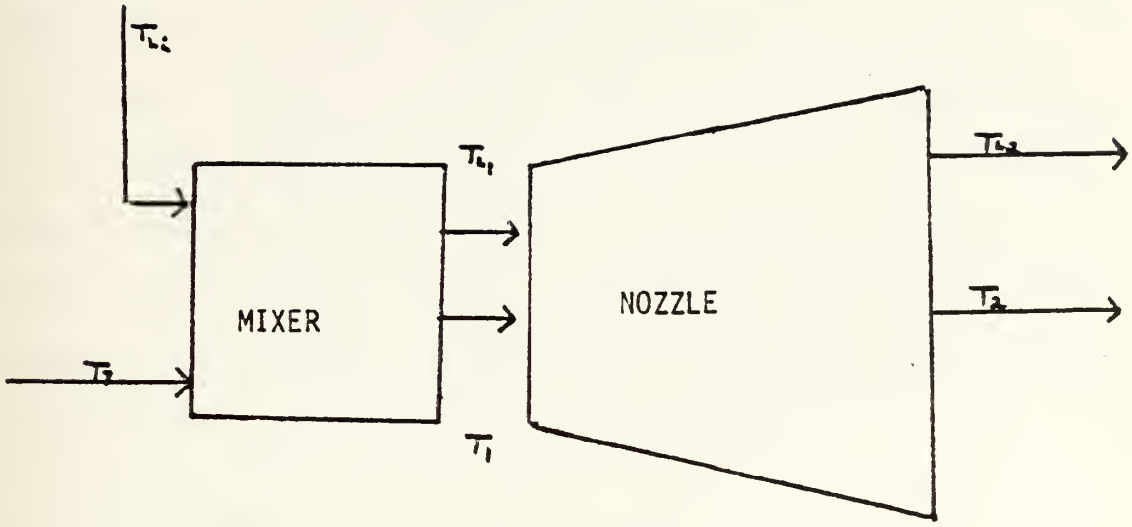


Figure 4. Liquid Impulse Turbine Schematic

expanded to a low pressure at the nozzle exit. The expanding vapor transfers momentum to the liquid droplets, while the droplets transfer heat to the vapor. This tends to aproach isothermal expansion through the nozzle, point 2. After leaving the nozzle, the liquid droplets are separated from the vapor by a rotary separator located on the turbine. The rotating drum turns at close to the nozzle's exit velocity. Hence there is very little friction loss between the separated liquid and the drum wall. The centrifugal acceleration produces a very clean separation of vapor and liquid. The liquid traveling with the rim of the rotating drum transfers axially through holes in the separator disc and subsequently enters the liquid turbine proper. The kinetic energy of the liquid is converted to shaft horsepower by the liquid turbine. Figure 5 illustrates the dual-phase liquid impulse turbine assembly. The vapor remains superheated as a consequence of the heat transfer from the liquid. The vapor flows from the separator, point 3, through a regenerator where heat is transferred to the condensate. The vapor is condensed, point 5; pumped to nozzle pressure, point 6; and passed through the regenerator for heating. Heat is added between point 6 and point 1 in two methods. The regenerator adds heat to the condensate by using the steam from the turbine rotor, point 7. The remainder of heat, point 7 to 1, is added by the heated liquid mixed with the condensate in the mixer. The water is vaporized by direct-contact heat transfer.



where T_{L_i} = Temp of liquid entering mixer

T_7 = Temp of water entering mixer

$T_{L_i} > T_1$

T_2 = Temp of steam leaving the nozzle

T_{L_2} = Temp of liquid leaving the nozzle

Figure 5. Temperature & State Point Diagram for the Mixture & Nozzle

In the nozzle most of the thermal energy of the steam is converted to kinetic energy of the liquid droplets. This acceleration of the liquid by the vapor in the two-phase nozzle provides the kinetic energy to drive the liquid impulse turbine. The liquid velocities involved are relatively low as compared to velocity of the vapor. Thus, the output of the impulse hydraulic turbine will be high torque/low rpm. This conversion of the liquid kinetic energy to shaft power at high torque with low rpm appears to have direct application to naval propulsion.

B. ONE-COMPONENT

A one-component system is one in which the working fluid is of the same chemical compound. One of the simplest dual-phase one-component systems is illustrated in Figures 6 and 7. The working fluid is heated to saturation temperature by some type of heat source. Heat sources applicable to this case are geothermal power plants, engine exhaust, industrial waste-heat recovery, and bottoming cycles for steam and gas turbine plants. This working fluid, at saturated liquid conditions, with small amounts of vapor is expanded through a two-phase nozzle. As the expansion process takes place ,the liquid partially vaporizes and accelerates the remaining liquid phase in the nozzle. The dual-phase mixture enters the rotary separator and the same process occurs as mentioned in section A. Since the liquid phase is of a much higher

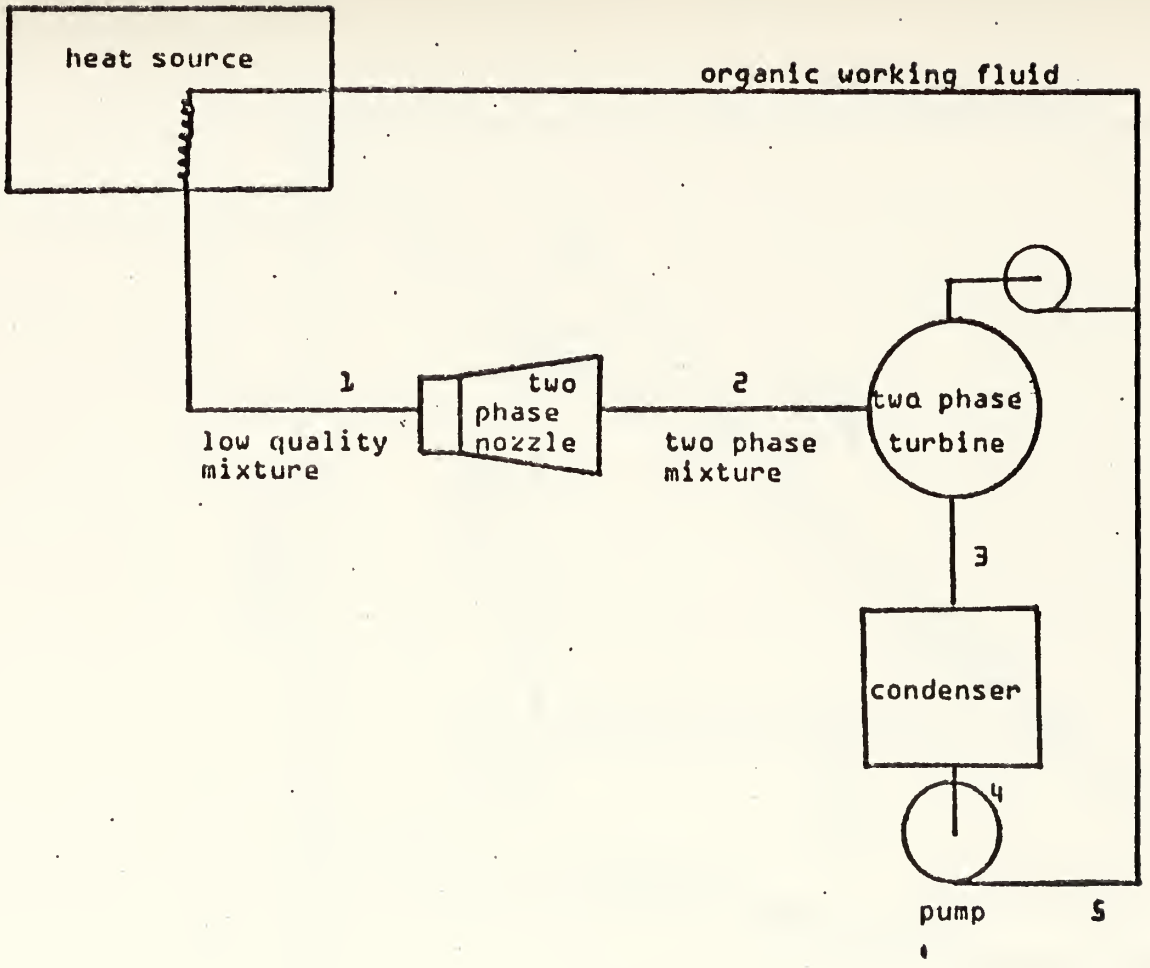


Figure 6. Dual-Phase Single-Component System

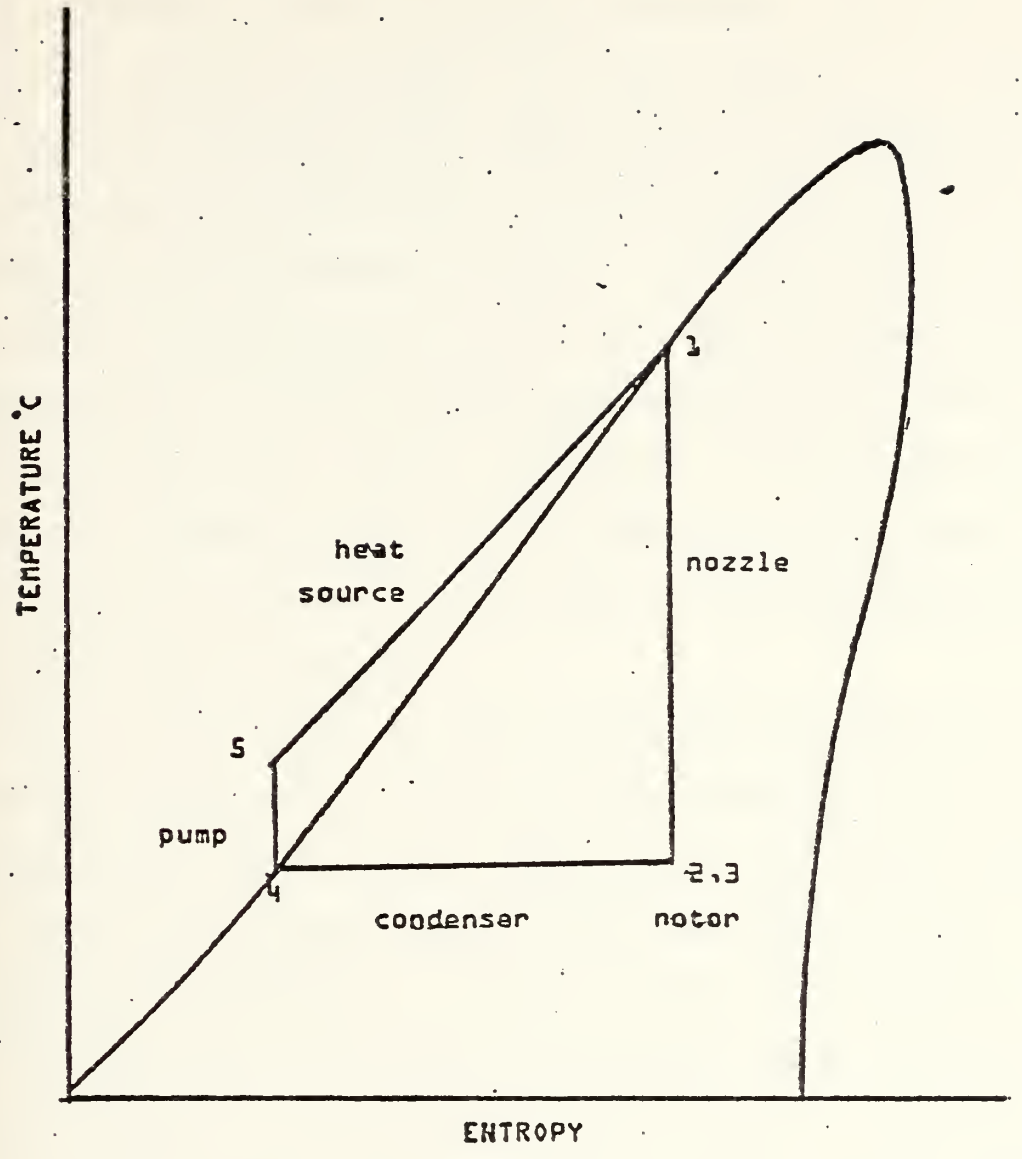


Figure 7. Dual-Phase Single-Component T-S Diagram

density than the vapor, the liquid velocities are relatively low as compared to the velocity of the vapor. Thus the output of the turbine will again have high torque at low rpm. After leaving the turbine the vapor mixture is condensed and the condensate is pumped back to the heat source. The cycle is shown on a T-S diagram in Figure 6. The state points are numbered to correspond with Figure 5. The dual-phase nozzle expansion takes the fluid from a saturated liquid, point 1, to a dual-phase flow, point 2. The flow is decelerated in the rotor; condensed, point 4; and pumped back to nozzle inlet pressure at point 5. The liquid is then reheated by the source fluid to point 1.

Another application of the one-component two-phase cycle is the wet-to-dry cycle. If the initial temperature of the working fluid is sufficiently high and the saturation curve has a positive saturated liquid slope the working fluid can be expanded to dry vapor. Figure 8 is the T-S diagram for a wet-to-dry cycle. The fluid is expanded from saturated liquid at point 1 to saturated vapor at point 2. The vapor drives an impulse rotor and leaves the rotor slightly superheated at point 3. The vapor is condensed to point 4 and pumped back to the nozzle inlet pressure at point 5.

C. ADVANTAGES

The advantage of the dual-phase cycle with respect to marine application is the ability to achieve low shaft speed

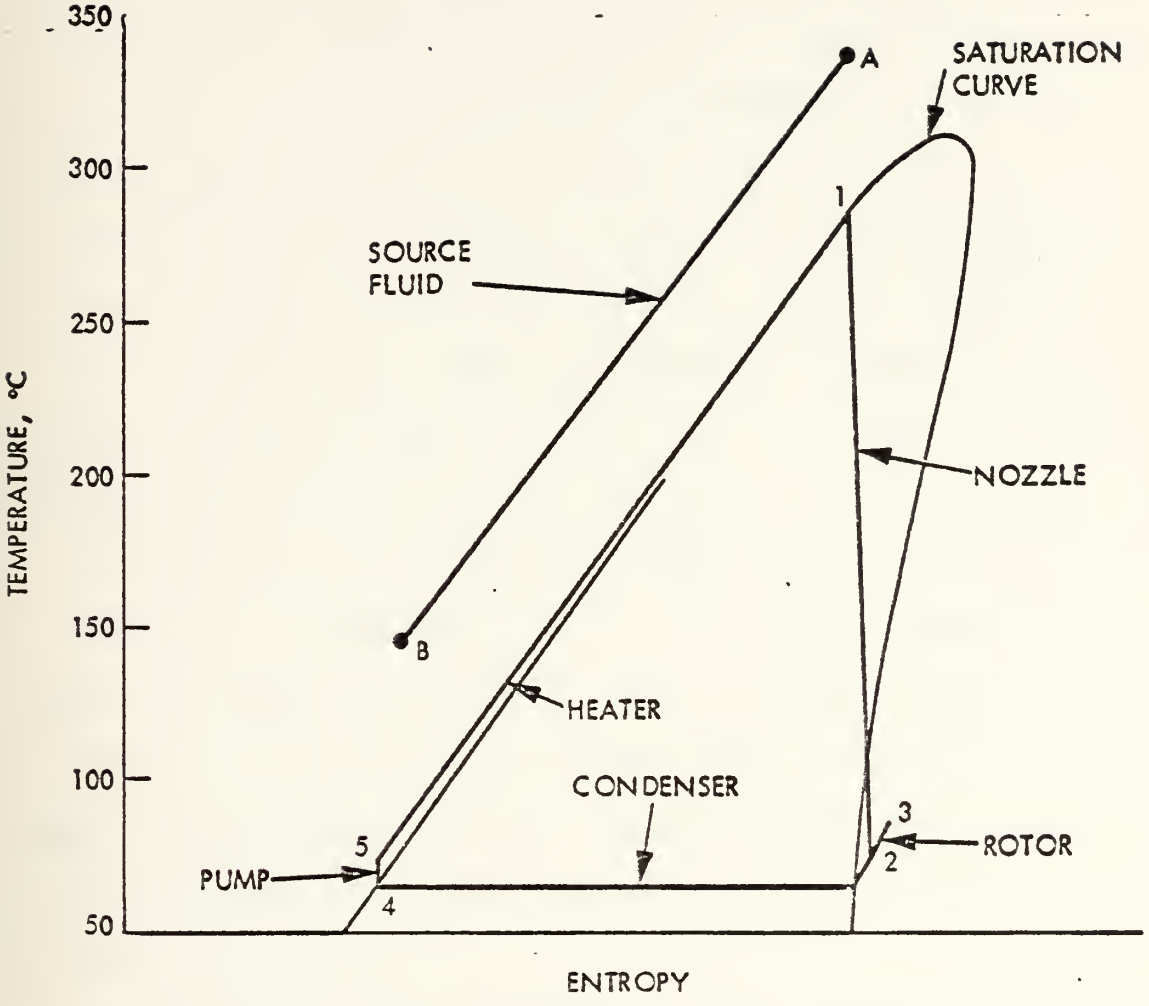


Figure 8. Wet-to-Dry T-S Diagram

in a small turbine engine. For example a steam turbine of 150-kw shaft horsepower using the temperature given in Figure 2 would have a speed of about 60,000 rpm. A comparable two-phase turbine would operate at approximately 10,000 rpm. There is also an efficiency advantage. At temperature corresponding to Figure 2, a steam Rankine cycle would have an efficiency of approximately 28% where-as the two-phase cycle would have an efficiency of 37%. This is assuming equal turbine efficiencies. The two-phase cycle also allows for control of turbine speed because the vapor/liquid mixture ratio can be varied to change the nozzle exit velocity. This is a capability unavailable in a conventional steam turbine.

Both of the dual-phase concepts can be thought of as a form of a regenerated Rankine cycle. The dual-phase cycle by control of liquid/vapor mixture ratio enhances the overall power system controlability. The T-S relationship for a dual-phase two-component engine cycle compared to a Rankine cycle is shown in Figure 9.

Two design studies References 1 and 2, have shown potential advantages in the two-phase engine cycle as compared to the conventional Rankine cycle for marine propulsion. The following advantages were noted:

1. High Efficiency - Full load output power performance gains ranging from 20 to 50 percent was found.

2. Direct Drive - Direct drive at speeds ranging from 90-4500 rpm was found possible with a single-stage turbine.

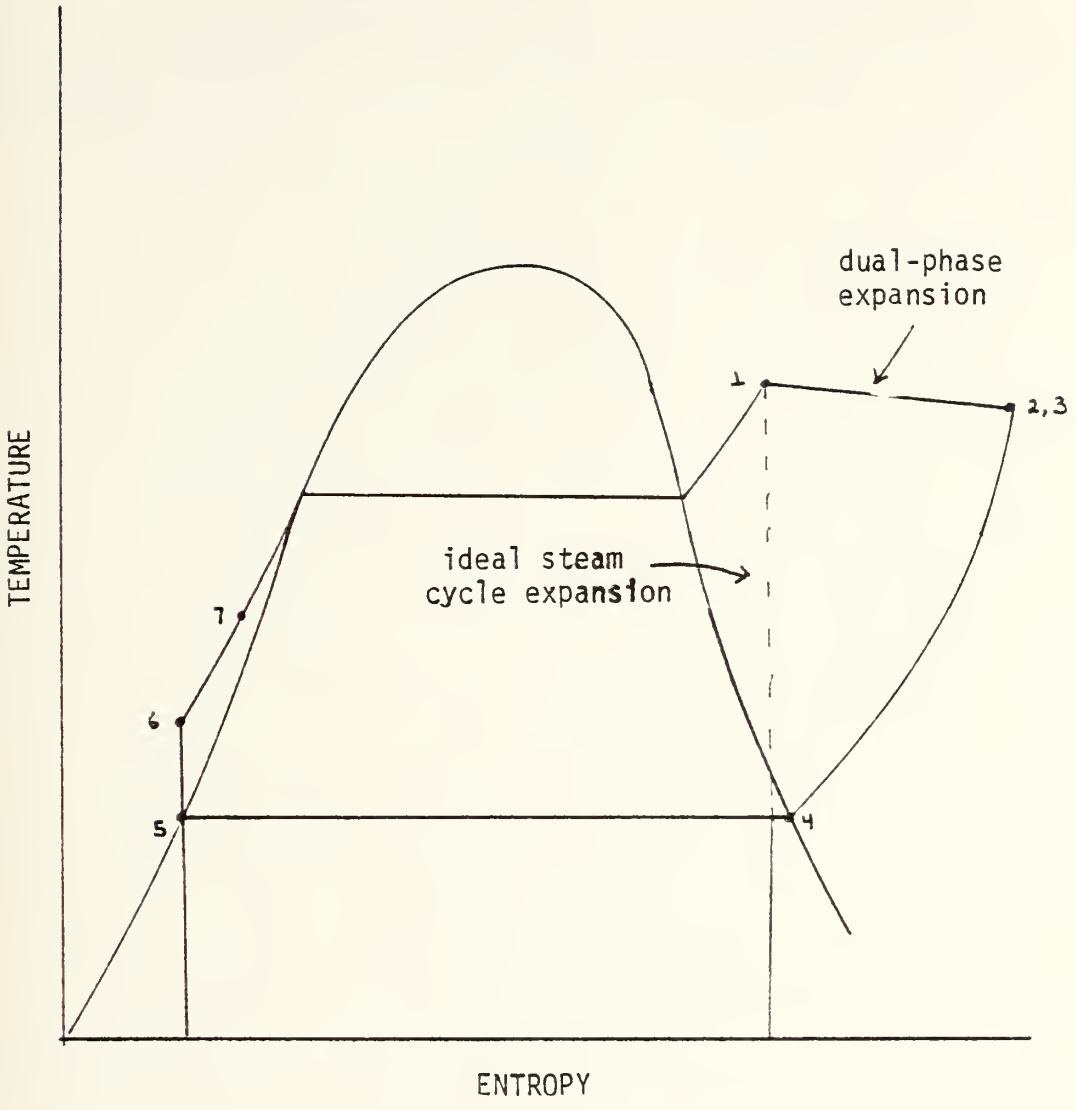


Figure 9. T-S Comparison of Dual-Phase Two-Component Cycle & Rankine Cycle

3. Reduced Volume - Volume reduction of 30 percent were estimated.

4. High Part-Load Efficiency - Variable mass ratio enabled part-load (cruise) efficiency gain of as much as 100 percent.

II. DUAL-PHASE NOZZLE THEORY

The flow phenomenon of a two-phase mixture has been analyzed in Reference 1. It is repeated as follows. The problem is illustrated in Figure 10. A spatially uniform two-component mixture of liquid drops and gas enters a nozzle at high pressure and low velocity and expands to low pressure and high velocity. The objective of the analysis is to determine, for a specified pressure the drop diameter D and the temperatures T_g and T_L, velocities V_g and V_L and flow rates $\dot{m}_g$ and $\dot{m}_L$ of the gas and liquid phases, respectively, at each station in the nozzle given the initial values of D, T_g, T_L, V_g, V_L, the total flow rate, and the properties of the fluids.

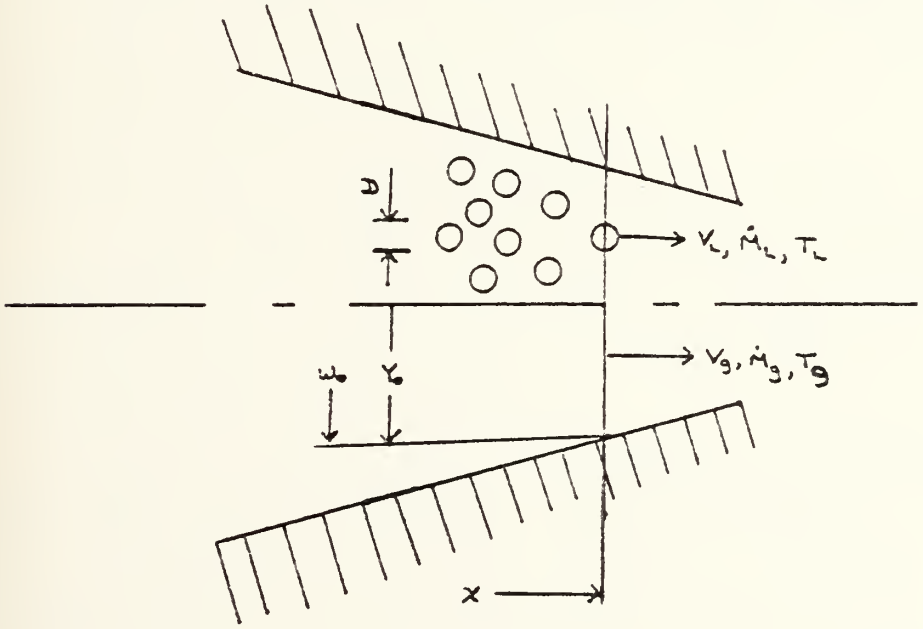


Figure 10. Dual-Phase Nozzle Flow Geometry & Nomenclature

The five relations employed to compute the five unknowns D, T_g, T_L, V_g, and V_L, are (1) the momentum equation for the mixture, (2) the energy equation for the mixture, (3) the drop drag equation, (4) the drop heat transfer equation, and (5) the drop breakup criterion. Solubility and vapor pressure relations provide the flow rate ratio $\dot{m}_g/\dot{m}_L$.

A. ASSUMPTIONS

The assumptions employed in the two-component analysis are as follows:

1. The liquid is uniformly dispersed as spherical drops all of the same diameter.
2. The drops break up to limit the Weber number to 6.
3. There are no external forces acting on the two-phase mixture other than pressure and wall shear, and there is no heat transfer to or from the mixture.
4. The flow is one-dimensional.
5. The drops are large enough for the surface curvature to have negligible effect on the vapor pressure of the liquid and for the surface energy to be negligible.
6. The drops are isothermal.
7. The gas mixture obeys the additive-pressure law.
8. The partial pressure of the predominantly liquid component in the liquid is given by Raoult's Law.
9. The concentration of the predominantly gaseous component in the liquid is given by Henry's Law.

10. The volume of the liquid solution is equal to the sum of the volumes of the pure liquids.

Assumption 1 restricts the analysis to nozzles having spatially uniform injection of the liquid into the gas and operating at gas-to-liquid volume ratios greater than unity. Assumption 2, the drop breakup criterion, states that drop diameter is limited to a value D for which $W_e = \rho_g V_g^2 D/2 = 6$. Thus

$$D_{max} = \frac{12\sigma}{\rho_g V_s^2} \tag{1}$$

where ρ_g is the gas density, V_s is the slip velocity $V_g - V_L$, and is the Liquid surface tension. The form of Eq. (1) is physically reasonable in that the Weber number is proportional to the ratio of stagnation pressure $\rho_g V^2_{\ s}/2$ to surface tension pressure 4V/D. Hence, a drop would be expected to flatten and breakup at a sufficiently high value of W_e. This has been verified experimentally and the critical Weber number found to be 6, within a factor of about two. An additional restriction is that for actual breakup to occur, the time spent at a Weber number exceeding 6 must be longer than the natural period of oscillation of the drop, $\pi(\rho_L D^3/\ )^{1/2}/4$, where ρ_L is the density of the liquid. This requirement is met only in two-phase nozzles longer than about 10 in. and Assumption 2 may cause the analysis to overestimate the exit velocity by increasing amounts as the nozzle length decreases below 10 in.

Assumption 3 excludes magnetohydrodynamic and mechanical body forces. The exclusion of wall heat transfer is correct for the insulated nozzles of interest for power systems. In addition, the relatively high velocity results in short residence lines in the nozzle proper.

Assumption 4 is closely met in practical nozzles since good performance requires small wall angles, large throat radius of curvature, and uniformly distributed injection of the fluids at the nozzle entrance.

Assumption 5 is valid for the drop sizes of 0.001 to 0.010 in. produced by the Eq. (1) breakup criterion. Assumption 6 is valid because of the rapid internal circulation in drops. Assumption 7 introduces negligible error in most cases of practical interest since the vapor pressure of the liquid is small and needs only to be evaluated approximately.

Assumptions 8, 9, and 10 are either valid, or cause little error, for fluids of low miscibility, which are the fluids of interest.

B. DERIVATION OF EQUATIONS FOR FREE-STREAM FLOW

1. Continuity

Referring to Figure 1, the nozzle flow area A is equal to the gas flow area $\dot{m}_g/\rho_g V_g$ plus the liquid flow area $\dot{m}_L/\rho_L V_L$. Thus

$$A = \dot{m}_g \left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l} \right) \tag{2}$$

where r is the mass mixture ratio $\dot{m}_L/\dot{m}_g$.

2. Momentum

By Assumption 3, the only force acting on the free-stream flow is that due to the pressure gradient. If $\dot{M}$ is the momentum flux at flow area A, the change in momentum flux across pressure increment dp is

$$d\dot{M} = -A\,dp \tag{3}$$

The momentum flux can be written as the sum of the momentum fluxes of the gas and liquid. Thus,

$$\dot{M} = \dot{m}_g V_g + \dot{m}_l V_l \tag{4}$$

If the flow were allowed to continue at constant pressure, V_g and V_L would become equal to each other at the mass-weighted mean velocity $\bar{V}$. Since for this process, $d\dot{M} = 0$, the value of $\bar{V}$ is given by

$$(\dot{m}_g + \dot{m}_l)\bar{V} = \dot{m}_g V_g + \dot{m}_l V_l \tag{5}$$

or

$$\bar{V} = \frac{V_g + rV_l}{1 + r} \tag{6}$$

Thus, the momentum flux can be written

$$\dot{M} = (\dot{m}_g + \dot{m}_l)\bar{V} \tag{7}$$

Since $\dot{m}_g + \dot{m}_L$ is constant, the change in momentum flux is

$$d\dot{M} = (\dot{m}_g + \dot{m}_l)d\bar{V} \tag{8}$$

Substituting Eqs. (8) and (2) into Eq. (3), $d\bar{V}$ can be written

$$d\bar{V} = -\frac{1}{1 + r}\left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l}\right) dp \tag{9}$$

The slip ratio is defined as

$$s = V_g/\bar{V} = (V_g - V_l)/\bar{V} \tag{10}$$

This equation can be combined with Eq. (6) to give V_g and V_L in terms of $\bar{V}$:

$$V_g = \left(1 + \frac{rs}{1+r}\right)\bar{V} = a\bar{V} \tag{11}$$

$$V_l = \left(1 - \frac{s}{1+r}\right)\bar{V} = b\bar{V} \tag{12}$$

The gas density can be expressed as

$$\rho_g = W_g p/RT_g \tag{13}$$

where W_g is the effective molecular weight of the gas mixture and R is the universal gas constant. Eq. (13) is the definition of the effective molecular weight W_g, which is the quantity that gives the actual gas density when substituted in Eq. (13).

Substituting Eqs. (11) - (13) into Eq. (9), the differential momentum equation is

$$2\bar{V}d\bar{V} = d\bar{V}^2 = -\frac{2}{1+r}\left(\frac{RT_g}{aW_g p} + \frac{r}{b\rho_l}\right)dp \tag{14}$$

The quantities a and b are slowly varying because s is typically only 0.1 to 0.3 and slowly varying. The quantities r, T_g, W_g and ρ_L are also slowly varying. Integrating

Eq. (14) over a pressure increment $\Delta\rho$, for which a, b, r, T_g, W_g, and ρ_L are constant to within the desired accuracy, the change in $\bar{V}^2$ is

$$\Delta\bar{V}^2 = -\frac{2}{1+r_m}\left(\frac{RT_{g_m}}{a_m W_{g_m}}\log_e\frac{p+\Delta p/2}{p-\Delta p/2}+\frac{r_m\Delta p}{b_m\rho_{l_m}}\right) \tag{15}$$

All quantities other than pressure can be taken outside the integral and evaluated at their mean values (denoted by sub script m) corresponding to the mid-interval pressure ρ. Thus,

$$\Delta\bar{V}^2 = -\frac{2}{1+r_m} \times\left(\frac{RT_{g_m}}{a_m W_{g_m}}\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}}\frac{dp}{p}+\frac{r_m}{b_m\rho_{l_m}}\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}}dp\right) \tag{16}$$

(16)

Performing the integrations,

$$\Delta\bar{V}^2 = -\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}}\frac{2}{1+r}\left(\frac{RT_g}{aW_g p}+\frac{r}{b\rho_l}\right)dp \tag{17}$$

Equation (17) is the final form of the momentum equation.

3. Energy

The enthalpy change of the mixture between state 1 (the beginning of pressure interval $\Delta\rho$) and state 2 (the end

of the interval) can be evaluated in two steps: (1) phase change at ρ_1, T_{g_1}, T_{L_1} and (2) change to ρ_2, T_{g2}, T_{L2}, at fixed composition.

The enthalpy change for step 1 is

ΔH_1	=	amount of A vaporized	X	enthalpy required to vaporize and heat unit mass of A from T_L to T_{gL}
	+	amount of B vaporized	X	enthalpy required to vaporize and heat unit mass of B from T_{L_1} to T_{g_1}
	+	amount of A and B	X	kinetic energy required to accelerate unit mass from V_{L_1} to V_{g_1}

or

$$\begin{aligned}\Delta H_1 = {} & (\dot{m}_{a_{g_2}} - \dot{m}_{a_{g_1}})\,[L_{a_1} + c_{a_{g_1}}(T_{g_1} - T_{l_1})] \\ & + (\dot{m}_{b_{g_2}} - \dot{m}_{b_{g_1}})\,[L_{b_1} + c_{b_{g_1}}(T_{g_1} - T_{l_1})] \\ & + (\dot{m}_{g_2} - \dot{m}_{g_1})(V_{g_1}^2 - V_{l_1}^2)/2\end{aligned} \tag{18}$$

where L and c are latent heat and specific heat, respectively.

Introducing more compact notation.

$$\begin{aligned}\Delta H_1 = {} & \Delta\dot{m}_{a_g}(L_{a_1} + c_{a_{g_1}}\delta_1 T) \\ & + \Delta\dot{m}_{b_g}(L_{b_1} + c_{b_{g_1}}\delta_1 T) + \frac{\Delta\dot{m}_g\delta_1 V^2}{2}\end{aligned} \tag{19}$$

The enthalpy change for step 2 is evaluated from the temperature, pressure, and velocity changes, with properties evaluated at mean T and ρ for the interval.

$$\Delta H_2 = \dot{m}_{g_2}\left[c_{g_m}(T_{g_2} - T_{g_1}) + \frac{1}{2}(V_{g_2}^2 - V_{g_1}^2)\right]$$
$$+ \dot{m}_{l_2}\left[c_{l_m}(T_{l_2} - T_{l_1}) + \frac{p_2 - p_1}{\rho_{l_m}}\right. \tag{20}$$
$$\left. + \frac{1}{2}(V_{l_2}^2 - V_{l_1}^2)\right]$$

$$= \dot{m}_{g_2}\left(c_{g_m}\Delta T_g + \frac{\Delta V_g^2}{2}\right)$$
$$+ \dot{m}_{l_2}\left(c_{l_m}\Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_l^2}{2}\right) \tag{21}$$

By Assumption 3, no work is done by the free-stream flow and no heat is transferred to it. Hence,

$$\Delta H_1 + \Delta H_2 = 0 \tag{22}$$

Substituting Eqs. (19) and (21) into Eq. (22) and solving for ΔT_g gives the energy equation for the mixture:

$$\Delta T_g = -\frac{1}{c_{g_m}}\left[\frac{\Delta V_g^2}{2} + r_2\left(c_{l_m}\Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_l^2}{2}\right)\right.$$
$$+ \frac{\Delta\dot{m}_g\delta_1 V^2}{2\dot{m}_{g_2}} + \frac{\Delta\dot{m}_{a_g}}{\dot{m}_{g_2}}\left(L_{a_1} + c_{a_{g_1}}\delta_1 T\right) \tag{23}$$
$$\left. + \frac{\Delta\dot{m}_{b_g}}{\dot{m}_{g_2}}\left(L_{b_1} + c_{b_{g_1}}\delta_1 T\right)\right]$$

4. Drag

Although no force other than pressure acts on the free-stream flow as a whole, a drag force exists between

the phases. Hence, a second momentum equation must be witten using as the control volume the boundary between the phases.

The two forces acting on each liquid drop are the buoyancy due to the pressure gradient and the drag due to the relative gas velocity. The sum of these is equal to the mass times the acceleration of the drop. Thus, for a single drop.

dynamic pressure of relative gas flow X drag coefficient X frontal area of drop

- volume of drop X pressure gradient = mass drop drop X acceleration of drop

or

$$\left(\frac{1}{2}\rho_g|V_s|V_s\right)C_D\frac{\pi D^2}{4}-\frac{\pi D^3}{6}\frac{dp}{dx}=\left(\frac{\pi D^3}{6}\rho_l\right)\left(V_l\frac{dV_l}{dx}\right) \tag{24}$$

The absolute value sign in the first term makes the drag force positive when $V_g > V_L$ and negative when $V_g < V_L$.

Solving Eq. (24) for dV_L,

$$dV_l=\frac{3\rho_g|s|s\bar{V}^2C_Ddx}{4\rho_lV_lD}-\frac{dp}{\rho_lV_l} \tag{25}$$

Differentiating Eq. (12), dV_L can also be expressed in terms of s, r, and $\bar{V}$. Thus,

$$dV_l = b\,d\bar{V} + \bar{V}\left[\frac{s\,dr}{(1+r)^2} - \frac{ds}{1+r}\right] \tag{26}$$

Solving for ds,

$$ds = \frac{b(1+r)\,d\bar{V}}{\bar{V}} + \frac{s\,dr}{1+r} - \frac{(1+r)\,dV_l}{\bar{V}} \tag{27}$$

Substituting dV_L from Eq. (25), noting that $d\bar{V} = d\bar{V}^2/2\bar{V}$, using Eq. (12), and writing for a finite increment, results in,

$$\Delta s = \frac{b_m(1+r_m)\,\Delta\bar{V}^2}{2\bar{V}_m^2} + \frac{(1+r_m)\,\Delta p}{b_m\rho_{l_m}\bar{V}_m^2} + \frac{s_m\Delta r}{1+r_m} - \frac{3\rho_{g_m}|s_m|\,s_m C_{D_m}(1+r_m)\,\Delta x}{4\,b_m\rho_{l_m}D} \tag{28}$$

This is the drag equation employed when x is specified as a function of ρ.

Solving Eq. (28) for Δ x yields the required alternative equation:

$$\Delta x = \frac{4D}{3\rho_{g_m}|s_m|\,s_m C_{D_m}\bar{V}^2}\left[\Delta p + \frac{b_m^2\rho_{l_m}\Delta\bar{V}^2}{2} + \frac{b_m\rho_{l_m}\bar{V}_m^2}{1+r_m}\left(\frac{s_m\Delta r}{1+r_m} - \Delta s\right)\right] \tag{29}$$

5. Heat Transfer

Although no heat is transferred to the mixture as a whole, heat transfer exists between the phases. Hence, a second energy equation must be written using as the control volume the boundary between the phases.

The work dW done on the liquid is that due to drag by the gas. (Only work done by shear or shaft forces is included in dW when writing the First Law for a control volume). Multiplying Eq. (24) by the number flow rate of drops $\dot{N} = 6\dot{m}_L/\pi D^3 \rho_L$, the drag force F_d on that quantity of liquid is

$$F_d = \frac{\dot{N}}{8}\rho_g |V_s| V_s C_D \pi D^2 = \frac{\dot{m}_l}{\rho_l}\frac{dp}{dx} + \dot{m}_l V_l \frac{dV_l}{dx} \tag{30}$$

The work done on the liquid is

$$-dW = F_d dx = \dot{m}_l \left(\frac{dp}{\rho_l} + \frac{dV_l^2}{2}\right) \tag{31}$$

The heat dQ transferred from the liquid is made up of two parts: (1) the convective cooling due to the temperature difference between the liquid and gas and (2) the evaporative cooling due to the latent heat supplied to the liquid vaporized. The convective cooling is

$$-dQ_c = hA_d\dot{N}(T_l - T_g)dt \tag{32}$$

where h is the heat-transfer coefficient, $A_d = \pi D^2$ is the surface area of a drop, and $dt = dx/V_L$ is the time required to traverse dx. Thus,

$$-dQ_c = \frac{6h\dot{m}_l(T_g - T_l)dx}{D\rho_l V_l} \tag{33}$$

The evaporative cooling is

$$-dQ_v = L_a d\dot{m}_{a_g} + L_b d\dot{m}_{b_g} \tag{34}$$

The change is enthalpy of the liquid over the pressure increment dp is

$$dH = \dot{m}_l\left(c_l dT_l + \frac{dp}{\rho_l} + \frac{dV_l^2}{2}\right) \tag{35}$$

Substituting Eqs. (31), (33), (34), and (35) into the steady-flow energy equation dQ - dW = dH, the result is

$$\frac{6h\dot{m}_l\delta T dx}{D\rho_l V_l} - L_a d\dot{m}_{a_g} - L_b d\dot{m}_{b_g} = \dot{m}_l c_l dT_l \tag{36}$$

where $\delta T = T_g - T_L$.

Writing for a finite interval, the final form of the drop heat-transfer equation is

$$\Delta T_l = \frac{1}{c_{l_m}}\left[\frac{6h\delta_m T\Delta x}{D\rho_{l_m}V_{l_m}} - L_{a_m}\frac{\Delta\dot{m}_{a_g}}{\dot{m}_{l_m}} - L_{b_m}\frac{\Delta\dot{m}_{b_g}}{\dot{m}_{l_m}}\right] \tag{37}$$

Equations (1), (17), (23), (23), and (37) are the five equations that must be solved simultaneously to obtain the values of the five dependent variables D, T_g, T_L, V_g, and V_L as a function of the independent variable p. To carry out the solution all quantities in the equations must be expressed in terms of these six variables.

C. WALL SHEAR AND BOUNDARY LAYER

For a two-phase nozzle, the momentum flux of the friction-less nozzle flow is that given by

$$\dot{M} = \dot{m}_t \overline{V}$$

The mean mixture density corresponding to the mean velocity $\overline{V}$ is

$$\rho' = \frac{\dot{m}_t}{A\overline{V}} = \frac{\rho_l}{1 + r_a} \tag{38}$$

where r_a is the ratio of gas flow area to liquid flow area $\rho_l V_l / r\rho_g V_g$.

From the definition of the momentum thickness, the value of ϑ at a station where the nozzle wall radius is y_o is given by

$$\dot{M} - \dot{M}_f = 2\pi y_o \theta \frac{\dot{m}_t \overline{V}}{A} = 2\pi y_o \rho' \overline{V}^2 \theta \tag{39}$$

where $\dot{M}_f$ is the momentum flux of the real flow with friction.

The skin-friction coefficient can be defined using the same quantities as single-phase flow

$$C_f = \frac{2\tau_w}{\rho' \bar{V}^2} \tag{40}$$

where τ_ω is the wall shear. It will be shown that a valid C_f value can be provided.

The boundary-layer momentum equation then becomes

$$d\theta = \frac{C_f}{2} dx - \theta \left[\frac{1 + (\delta^*/\theta)}{\bar{V}} d\bar{V} + \frac{1}{\rho' \bar{V}} d(\rho' \bar{V}) + \frac{1}{R_w} dR_w \right] \tag{41}$$

where δ^* is the displacement thickness, i.e., the distance the wall must be moved outward to give the same flow rate as with frictionless flow.

Assuming a $\frac{1}{7}$ power velocity profile and no density variation, the shape factor δ^*/θ is obtained from

$$\frac{\delta^*}{\theta} = \frac{\int_0^\delta [1 - (y/\delta)^{1/7}]\, dy}{\int_0^\delta (y/\delta)^{1/7} [1 - (y/\delta)^{1/7}]\, dy} = \frac{9}{7}$$

where δ is the velocity thickness of the boundary layer.

Noting that $d\bar{V}$ can be written $d\bar{V}^2/2V$, and that $d(\rho'\bar{V}) = d(m_t/A)$, the finite-difference form of Eq. (41) is

$$\Delta\theta = \frac{C_{f_m}}{2} \Delta x - \theta_m \left(\frac{8}{7\bar{V}_m^2} \Delta\bar{V}^2 - \frac{1}{A_m} \Delta A + \frac{1}{y_{o_m}} \Delta y_o \right)$$

Wall shear in homogeneous two-phase flow has been found to be equal to that which would exist with pure liquid at equal velocity and boundary-layer thickness, multiplied by the wetted wall fraction:

$$\tau_w = \frac{C_{f_l}}{2} \rho_l V_l^2 \frac{A_l}{A} = \frac{C_{f_l} \rho_l V_l^2}{2(1 + r_a)} \tag{42}$$

where C_{f_l} is the skin friction coefficient for liquid at a Reynolds number of

$$R_\delta = \frac{\rho_l V_l \delta}{\mu_l}$$

For a 1/7-power profile, the velocity thickness,

$$\delta = \frac{72}{7} \theta$$

A convenient relation for C_{f_l} as a function of R_δ is the Shultz-Grunow relation which can be written

$$C_{f_l} = \frac{0.208}{(\log_{10} R_\delta + 0.425)^{2.584}}$$

Comparison of Eqs. (40) and (42) shows that C_f can be written

$$C_f = \frac{rb}{1 + r} C_{f_l}$$

Thus, the final form of the boundary-layer momentum equation is

$$\Delta\theta = \frac{r_m b_m}{1 + r_m} \frac{C_{f_l} \Delta x}{2} - \theta_m \left(\frac{8 \Delta \bar{V}^2}{7 \bar{V}_m^2} - \frac{\Delta A}{A_m} + \frac{\Delta y_o}{y_{o_m}} \right)$$

Let $\overline{V}_\delta$ be the mean velocity of the flow including the boundary layer. Then, from Eq. (39),

$$\dot{m}_t \overline{V}_\delta = \dot{M}_f = \dot{m}_t \overline{V} - 2\pi y_o \rho \overline{V}^2 \theta$$

Hence, employing Eq. (38), the mean exit velocity including the boundary layer is

$$\overline{V}_\delta = \overline{V}\left(1 - \frac{2\pi y_o \theta}{A}\right)$$

By the definition of the displacement thickness, the flow rate is reduced by the throat displacement thickness δ_t^* to

$$\dot{m}_\delta = \dot{m}_t\left(1 - \frac{2\delta_t^*}{y_{o_t}}\right)$$

D. NOZZLE THEORY SUMMARY

The preceding equations form the basis for the mathematical model which is used to predict, based on inlet conditions, the exit velocity, and temperature of the mixture. These equations also form the basis for the model which provides the optimum nozzle shape given a set of inlet conditions. Some additional relationships are, however, required. These are:

1. Phase properties - to establish the mass ratio, mass flow rate ratio of gas to liquid, and the thermal conductivity of the mixture.

2. Liquid drop drag coefficients.
3. The liquid drop heat transfer coefficients.
4. Boundary layer momentum thickness and displacement thickness.
5. Skin friction coefficient.

These five additional relationships are developed in detail in Reference [1].

III. COMPUTER PROGRAM DUAL-PHASE NOZZLE

The computer program employed in this study is based on a program developed by Dr. G. Elliott of the Jet Propulsion Laboratory in Pasadena, California. The program was updated and converted for use on the Naval Postgraduate School computer. The Dual-Phase Two-Component program employs the theory in Section II. The program is written in Fortran computer language and can be compiled using a Watfiv or Fortran IV compiler.

This program has been utilized in dual-phase nozzle analysis and to provide values for comparison with the experimental results. To use the computer program the inlet conditions have to be specified. The flow conditions are: inlet pressure; mass ratio; inlet temperature of the gas and liquid; inlet velocity of the gas and liquid; total mass flow rate; and nozzle exit pressure. Section III B, shows specified details for data input.

There are two options that can be chosen. The first is prescribed pressure-versus-distance option MOP=0. The pressure profile P(X) is selected corresponding to the adopted nozzle contour. If the pressure-versus-distance is used a P(X) input table is required. This profile is developed from the actual measured pressure values in the experiments.

(See Appendix A for sample program.) The second option consist of an optimum nozzle contour option MOP=1. This option is useful only when the liquid drop diameter is constant.

The dual-phase two-component computer program is a structured program with thirteen subroutines controlled by a main program. This arrangement improved the programming process through better organization and programming notation.

The control point of the dual-phase two-component computer program is the "main section." It controls the flow path and operation of all input data, property tables, and calculations. It accomplishes this by calling the thirteen subroutines at the appropriate times, saving wanted data in files, and printing out desired information.

One of the most important subroutines which inputs information is the "INTRP" subroutines. INTRP controls the property table inputs. It reads in four two-dimensional tables and fourteen one-dimensional tables. These inputs are the properties of the gas and liquid phases of both components of the flow in the nozzle. The subroutine writes the values of these tables into a file and retrieves appropriate values from that file. INTRP can also interpolate for values used throughout the entire program.

Input of case data is controlled by subroutine "Sect 1." Identification information and case heading information is read and printed for each instance. Sect 1 also places the pressure vs. distance profile, if specified, in an array.

"Sect 2" through "Sect 6" are the subroutines which calculates the flow data. Sect 2 sets the initial conditions indicated in the input, and begins the iterations. Sect 3 computes initial flow rates of both components; the initial area of the nozzle; slip velocity; mean free stream velocity; and slip friction. Sect 4 computes the changes in flow parameters and new distances. It then begins to calculate new conditions such as flow rate, temperature, velocities, surface tension and mean area. Sect 5 is the binary cut convergence routine and computes mean boundary-layer parameters.

If a problem is diagnosed in any subroutines and "diagno" is called, it will print all output parameters calculated to that point. It also does the same if there is a convergence problem.

There are two subroutines that output calculated data, subroutine "Write" and subroutine "Output." Subroutine "Write" will send output information to the printer for a hard paper copy. Subroutine "Output" reads and stores the output on a file.

The two-phase two-component program has been written with comment statements in the text of the program. These will allow for a more understandable and, therefore, a more easily modified program. For specific details on the content of these subroutines, see Appendix M.

The dual-phase nozzle program was tested for correct output. Sample data and results were obtained from

Dr. David Elliott, were inputted into the program, and executed. The output was compared to the sample data. The program produced duplicate results.

The program begins by storing fluid property tables and reading in all input data. All nozzle inlet conditions are computed. The program then proceedshalf a pressure step at a time. At the middle of each pressure interval, the changes in quantities across the interval are computed using the properties interpolated from the table for that pressure, and for the existing temperature. The change in slip is found if the pressure profile P(X) is specified. At the end of each pressure step, the flow conditions are updated and initial conditions are determined for the next step. The dropsize is reduced at the point when the Weber number exceeds six. The flow conditions are printed if the pressure is one selected for output. The computation continues until the last pressure step has been completed and flow conditions at the smallest flow area encountered are printed as the throat conditions.

A. PROPERTY TABLES

1. Heat capacity of component "A" vapor in BTU/LBM-R is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 heat capacity (BTU/LBM-R)

25-36 pressure (psi)

37-48 heat capacity (BTU/LBM-R)

49-60 pressure (psi)

61-72 heat capacity (BTU/LBM-R)

The maximum entries of temperature are 35 values. For each value of temperature, the maximum number of entries of pressure and heat capacities are 35 values. Each row of this table will be terminated with the pressure and heat capacity equal to 10^5. These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix B can be used to determine the values of heat capacities. The program structures its output in the format needed for the table input. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 heat capacity at .01 P

15-21 heat capacity at .4 Pa

22-28 heat capacity at .7 Pa

29-35 heat capacity at 1.0 Pa

34-42 heat capacity at 4.0 Pa

43-49 heat capacity at 7.0 Pa

50-56 heat capacity at 10.0 Pa

57-63 heat capacity at 40.0 Pa

64-70 heat capacity at 70.0 Pa

The temperature must be entered with increasing value.

2. Heat capacity of component "B" gas, BTU/LBM-R is a function of temperature and pressure. This two-dimensional table has the same format as part A1 above.

3. Molecular weight of component "A" vapor is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 molecular weight

25-36 pressure (psi)

37-48 molecular weight

49-60 pressure (psi)

61-72 molecular weight

The maximum number entries of temperature are 35 values. For each value of temperature, the maximum entries of pressure and molecular weight are 35 values. Each row of this table will be terminated with the pressure and molecular weight equal to 10^5. These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix C can be used to determine the values of molecular weight. The program formats its output in the format needed for the table input of the two-component two-phase computer program. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. The program used in Figure 8 can only be used with ideal gases. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 density at .01 P

15-21 density at .4 Pa

22-28 density at .7 Pa

29-35 density at 1.0 Pa

34-42 density at 4.0 Pa

43-49 density at 7.0 Pa

50-56 density at 10.1 Pa

57-63 density at 40.0 Pa

64-70 density at 70.0 Pa

The temperatures must be entered with increasing value.

4. Molecular weight of component "B" gas is a function of temperature and pressure. This two-dimensional table has the same format as part A3 above.

5. There are fourteen one-dimensional tables. The one-dimensional tables are entered in the following format (for Z(T)):

Card 1: (format 6E12.6)

cols.

1-12 Ti-2, oR

13-24 Ti-2

25-36 Ti-1 $2 \leq i \leq 50$

37-48 Zi-01

49-60 Ti

61-72 Zi and Tj-1 < Tj for $2 \leq j \leq 50$

Each table is terminated by two consecutive entries of 10^5, i.e., Tk ≡ Zk ≡ 10^5 (1.0E5 right adjusted in the field). The fourteen one-dimensional tables are (in order requested):

1. CAL(T) heat capacity of component A liquid, BTU/LBM oR
2. CBL(T) heat capacity of component B liquid, BTU/LBM oR
3. LA(T) latent heat of vaporization for component A, BTU/LBM
4. LB(T) latent heat of vaporization for component B, BTU/LBM
5. PBO(T) vapor pressure of component B
6. ROAL(T) density of liquid component A, LBM/FT3
7. ROBL(T) density of liquid component B, LBM/FT3
8. KAG(T) thermal conductivity of component A gas, BTU/FT HR oR
9. KBG(T) thermal conductivity of component B gas, BTU/FT HR oR

10. VIAL(T) viscosity of liquid component A, LBM/FT HR

11. VIBL(T) viscosity of liquid component B, LBM/FT HR

12. VIAG(T) viscosity of gas component A, LBM/FT HR

13. VIBG(T) viscosity of gas component B, LBM/FT HR

14. SIG(T) surface tension of liquid component B, DYNE/CM

Appendix D gives sample property table for input.

B. CASE INPUT

A blank card must separate the property table from the data set decks following.

Card 1: (format 4A4, A2, 3A4, 7A4, A32, 2I6)

cols.

1-18 date

19-30 case number, may be any alphanumeric data

31-60 identification

61-66 NS, number of pressure steps per printout

(right justified integer).* Use -1 if new property tables follows.

57-72 NP, number of printouts (right justified)

Card 2: (All integers right justified in field)
(format 1116)

cols.

1-6 MBU, =0 constant droplet size, =1 drop breakup

7-12 MOP, =0 X(P) table to be supplied, =1 X(P) is to be optimized

13-18 MGEO, =0 circular, =1 annular

19-24 NDS, maximum number of S iterations

25-30 NSO, maximum number of So iterations

31-36 NB, maximum number of TB iterations

37-42 NNS, first setting of step counter

Card 3: (format 5E12.6)

cols.

1-12 DP, pressure step size, negative for decreasing, psi

13-24 RC, mass flow ratio

25-36 PHI, angle of annular nozzle axis, deg

37-48 RAXO, annular nozzle axis, in.

49-60 EMT, total flow rate *P final = PO + (NS*NP-NNS-1)*DP+DP1

Card 4: (format 6E12.6)

cols.

1-12 H, inverse Henry's Law constant, psi

13-24 ALAM, Lagrangian multiplier

25-26 DPL, first pressure step size

37-48 WAL, molecular weight of liquid a

49-60 WBL, molecular weight of liquid b

61-72 SA, Sutherland constant for component A, oR

Card 5: (format 6E12.6)

cols.

1-12 SB, Sutherland constant for component B, oR

13-24 DO, initial drop diameter, in.

25-36 PO, initial pressure, psia

37-48 TGO, initial gas temperature, oR

49-60 TLO, initial liquid tempeature, oR

61-72 VGO, initial gas velocity, FT/S

Card 6: (format 6E12.6)

cols.

1-12 VLO, Initial liquid velocity, FT/S

13-24 THOO, initial momentum thickness of outer wall boundary layer, in.

25-36 THIO, initial momentum thickness of inner wall boundary layer, in.

37-48 EDS, convergence criterion for S

49-60 ESO, convergence criterion for So

61-72 EB, convergence criterion for T, oR

If MOP=0, the following cards are present:

in 10 Card 7: (format 7A4, A2) cols.

1-30 X(P) table identification (and alphanumeric data).

Card 8: (format 6E12.6)

cols.

1-12 pressure, pi-2, psia

13-24 distance, xi-2, in.

25-36 pressure, pi-1 $3 \leq i \leq 75$

37-48 distance, xi-1

49-60 pressure, pi

61-72 distance, xi

The last two entries are 1.0E5 and 1.0E5 right adjusted in their fields. The table must be monotonic increasing or decreasing. New property tables may be used by putting -1 in cols. 61-66 of Card 1, and following this with new property tables and data sets. Appendix E is a sample input data.

C. OUTPUT

For each case, the case identification is printed followed by the input parameters. If MOP=0, the X(P) table forms a part of this output. The following output then appears.

1. X distance, in.
2. P pressure, psia
3. R mass flow ratio
4. vb mean free-stream velocity, ft/s
5. a flow area, in. 2

6. tb gas temperature, or
7. tl liquid temperature, or
8. vg gas velocity, ft/s
9. vl liquid velocity, ft/s
10. vs slip velocity vg-vl, ft/s
11. s slip fraction vs/vb
12. d drop diameter, in.
13. rv ratio of gas volume flow to liquid volume flow
14. ra ratio of gas flow area to liquid flow area
15. alpha mass fraction of component a dissolved in liquid
16. beta mass fraction of component b vapor in gas
17. mg gas flow rate, lbm/s
18. ml liquid flow rate, lbm/s
19. rog gas density, lbm/ft3
20. rol liquid density, lbm/ft3
21. wag molecular weight of component a gas
22. wbg molecular weight of component b gas
23. wg mean molecular weight of gas
24. pa partial pressure of component a, psia
25. pb partial pressure of component b, psia
26. la latent heat of vaporization of component a, btu/lbm
27. lb latent heat of vaporization of component b, btu/lbm

28. sigma liquid surface tension, dyne/cm
29. cgm specific heat of gas (at midpoint of pressure step), btu/lbm of
30. clm specific heat of liquid, btu/lbm of
31. vigm viscosity of liquid, lbm/ft hr
32. vilm viscosity of gas, lbm/ft hr
33. kgm thermal conductivity of gas, btu/hr ft of
34. rem reynolds number of flow over drops
35. cdm drag coefficient of drops
36. hm heat transfer coefficient of drops, btu/hr ft2
37. rb mass flow ratio after velocity and temperature equalization
38. ab flow area after equalization, in. 2
39. tb temperature after equalization, or
40. rvb volume flow ratio after equalization
41. alphb alpha after equalization
42. betab beta after equalization
43. mgb gas flow rate after equalization, lbm/s
44. mlb liquid flow rate after equalization, lbm/s
45. vilb liquid viscosity after equalization, lbm/ft hr
46. rogb gas density after equalization, lbm/ft3
47. rolb liquid density after equalization, lbm/ft3
48. wagb molecular weight of component a gas after equalization

49. wbgb molecular weight of component b gas after equalization
50. wgb mean molecular weight of gas after equalization
51. pab partial pressure of component a gas after equalization, psia
52. pbb partial pressure of component b gas after equalization, psia
53. g separator friction parameter
54. ref separator film reynolds number
55. yo distance from nozzle axis to outer wall, in.
56. wom angle of outer wall relative to axis, deg
57. tho momentum thickness of outer boundary layer, in.
58. delo velocity thickness of outer boundary layer, in.
59. delso displacement thickness of outer boundary layer, in.
60. redom reynolds number of outer boundary layer
61. cfom skin friction coefficient of outer boundary layer
62. twom shear stress on outer wall, psi
63. vbd mean velocity including boundary layer, ft/s
64. wim angle of inner wall relative to axis, deg
65. thi momentum thickness of inner boundary layer, in.
66. deli velocity thickness of inner boundary layer, in.
67. delsi displacement thickness of inner boundary layer, in.

68. redim reynolds number of inner boundary layer

69. cfim skin friction coefficient of inner boundary layer

70. twin shear stress on inner wall, psi

71. nna number of iterations required to optimize X(P)

72. nis number of iterations required to converge cn s or so

73. nib number of iterations required to converge on tb

IV. EXPERIMENTAL SYSTEM

The experimental system can be grouped into three subsystems. These are:

a) nozzle

b) air supply system

c) liquid injection system

Each subsystem is described in the following sections. Figure 11 is an overall system schematic.

A. NOZZLE

The nozzle has a convergent-divergent flow passage. It is 12 inches long with a variable exit area. The exit area can be varied from .45313 square inches to .84375 square inches. The pivot point is located 1 inch above the throat. This causes the throat to vary when the exit is varied. Since the change in the throat is negligible, it will be considered to be constant. It has a throat area of .45 square inches. The inlet area is 1.625 square inches. The throat is located 4 inches from the inlet. The nozzle is constructed by sandwiching two 1/2 inche thick machined aluminum nozzle profile plates between 1/2 inch plexiglas plates (Fig. 12). The aluminum nozzle plates are located at the end of a 30 inch long entry section and are easily adjustable. Figure 13 shows a close up of the aluminum section of the nozzle.

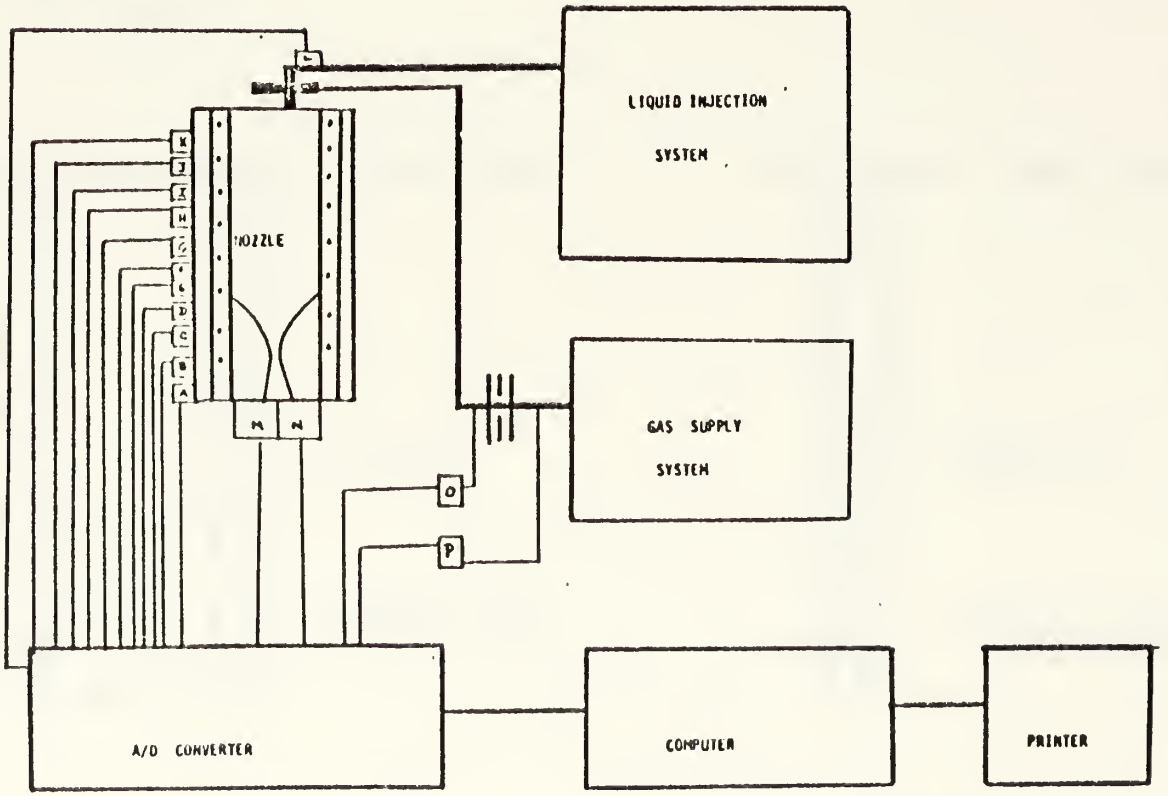


Figure 11. Experimental System Schematic

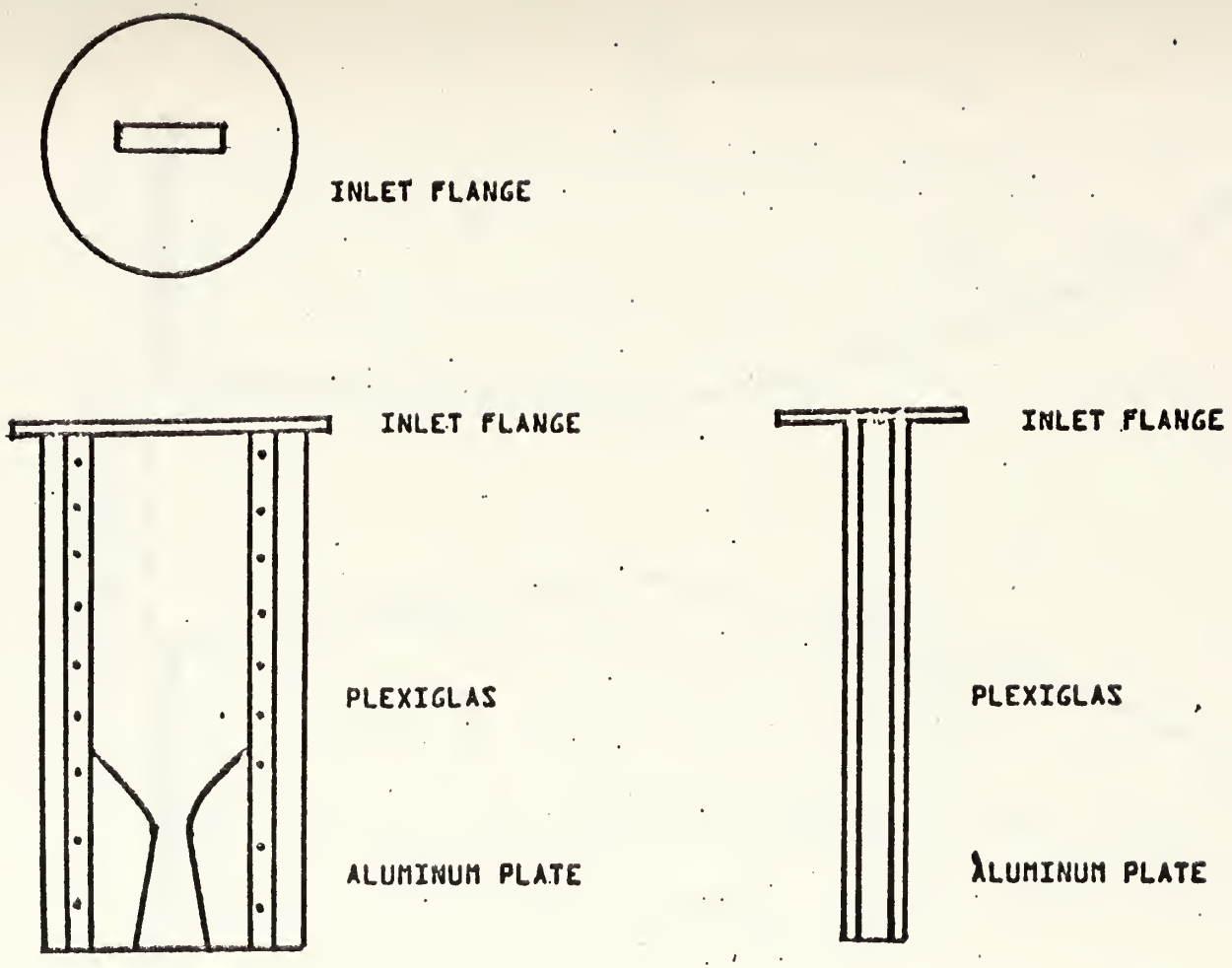


Figure 12. Nozzle Assembly Drawing

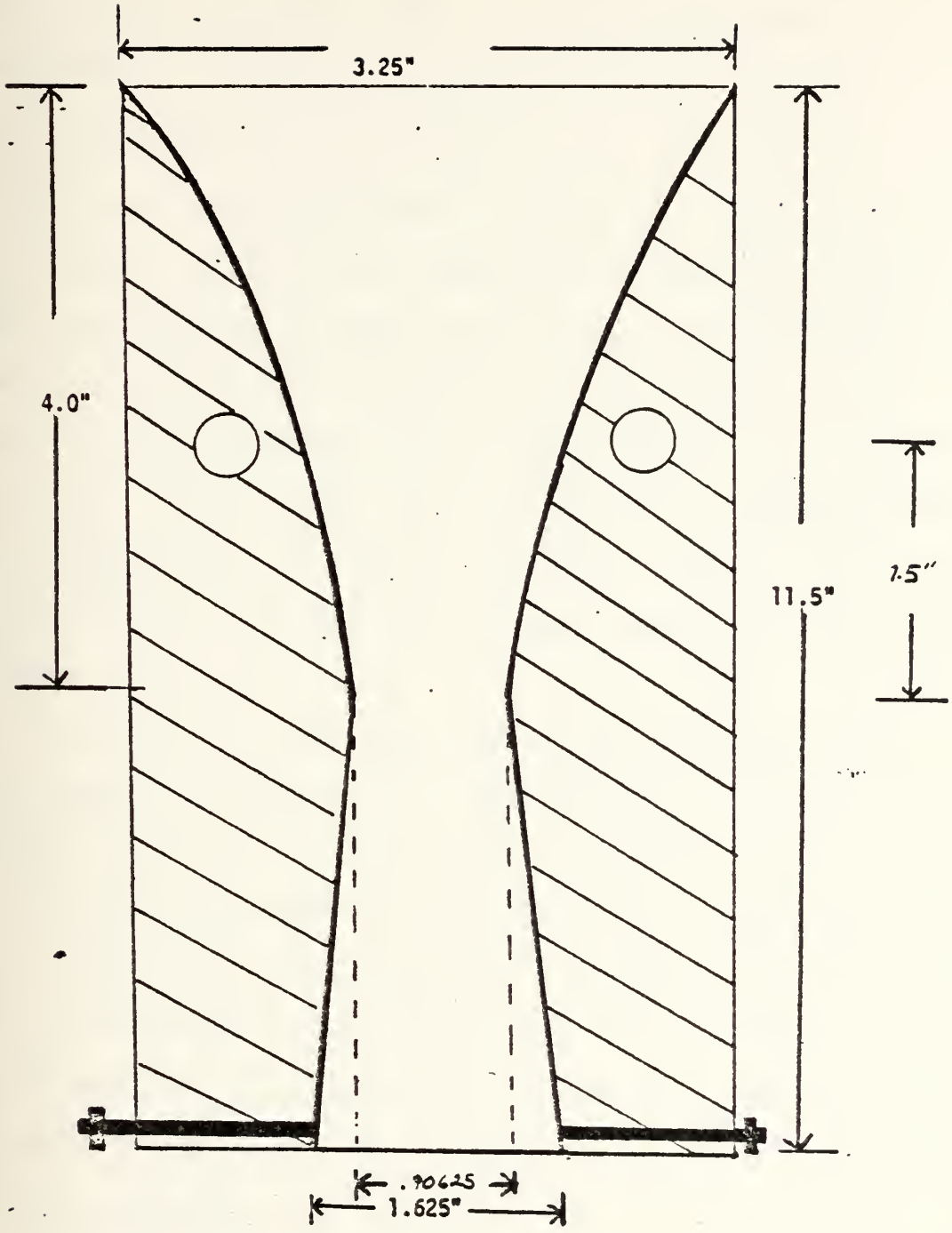


Figure 13. Nozzle Geometry Schematic

The inlet section provides the necessary space for pressure taps, liquid injection tubes, and other instrumentation and configuration options.

B. AIR SYSTEM

The air system is shown in Figure 14. Two 117 cubic feet tanks supplied with compressed air from an Ingersol Rand two-stage air compressor provides the air storage volume required to support the nozzle's operation. Each storage tank has a pneumatically control Norgren gate valve at its exit. These valves are operated by a nitrogen actuator and controlled by a pressure regulator. The nitrogen is regulated to 40 psi control pressure which will open the Norgren valve.

The nozzle is supplied with air via a 3" i.d. pipe. The air supply to the nozzle is controlled by a solenoid actuated nitrogen operated 3 inch ball valve. The nitrogen is supplied via a regulator. By varying the nitrogen supply pressure to the ball valve, supply air pressure to the nozzle can be controlled. Air flow to the nozzle is measured with a standard ASME orifice plate. Figure 15 shows the dimensions of the orifice. The orifice is a model D-10512 with a 0.920 inch bore.

C. LIQUID INJECTION SYSTEM

The liquid injection system, Figure 16, is supplied by house water and is further pressurized by an Aurora electric

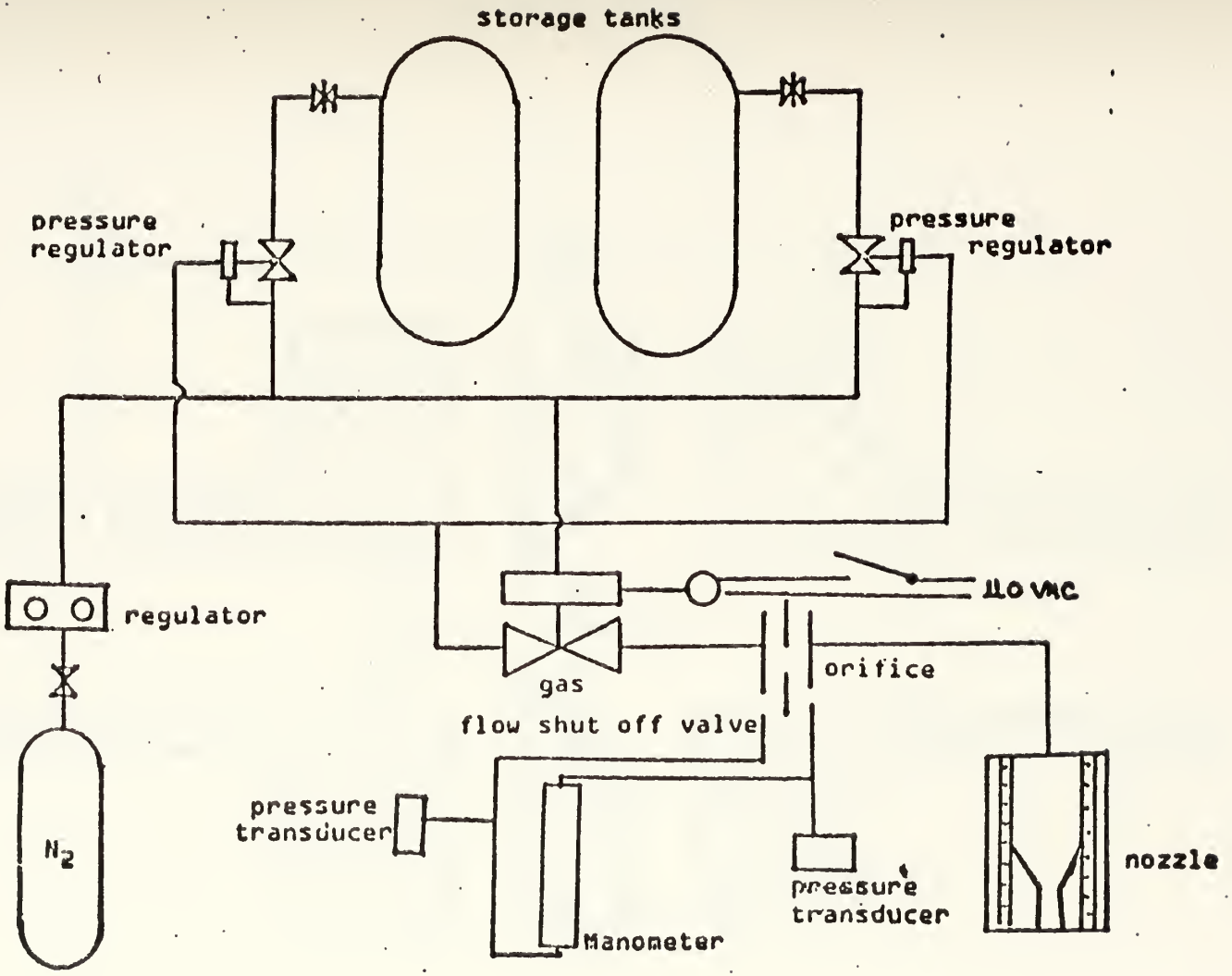


Figure 14. Orifice Schematic

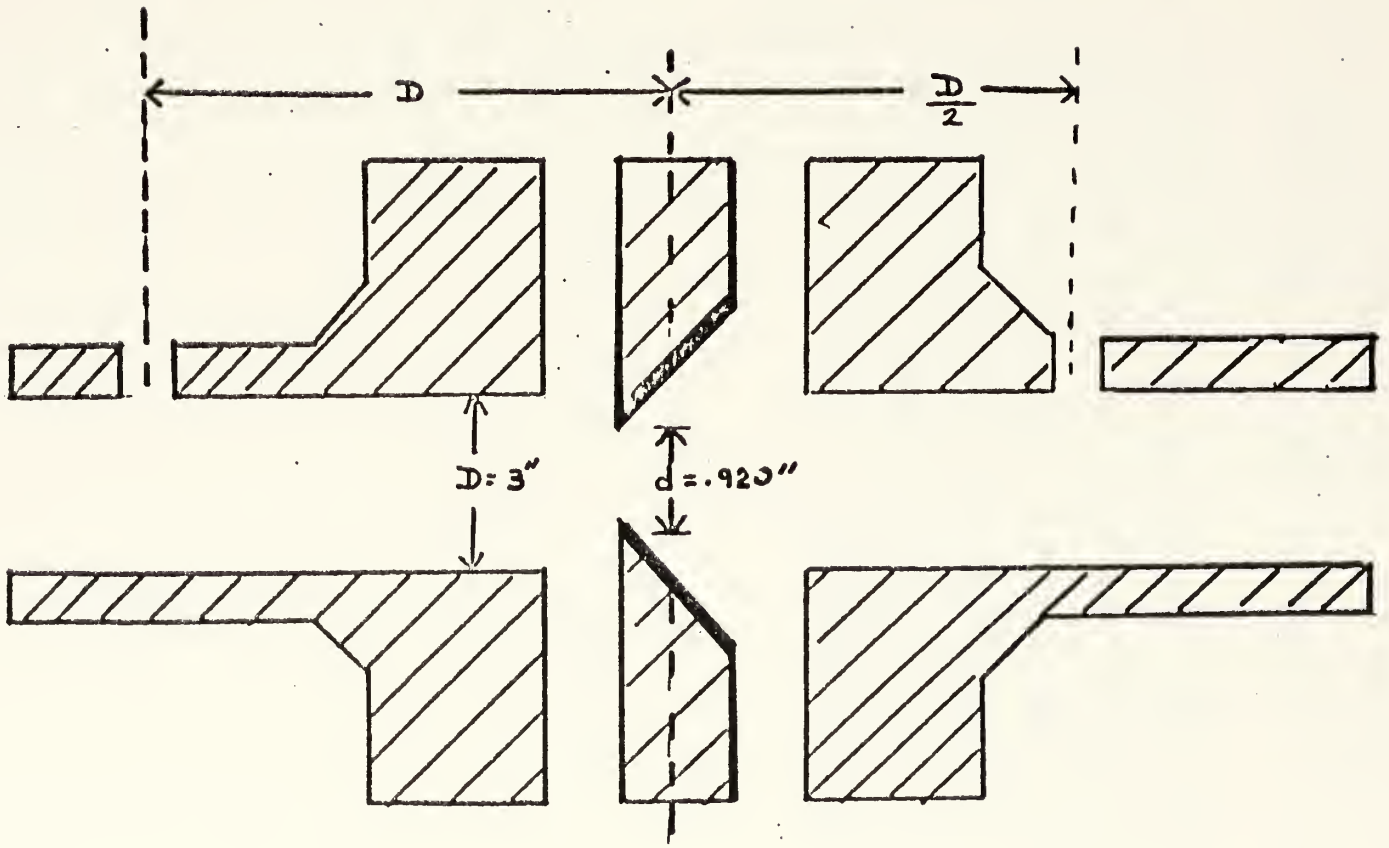


Figure 15. Air System Schematic

pump model/type 317696. The pump is rated at 50 gallons per min. The pump supplies pressurized water to the injection tube via two flowmeters (rotometers). The flowmeters are F&P co. precision bore flowrator tubes. One rotometer is rated at 1 to 12 gallons per min. and the other at .6 gallons per min.

The liquid injector is a 0.25 inch brass tube inserted in the 3" i.d. air supply pipe just upstream of the flange connection to the test section. The injector tube is drilled with sixteen 1/16th inch diameter holes facing the test section entrance. The drilled holes were made as small as possible consistent with achieving a significant liquid mass flow rate.

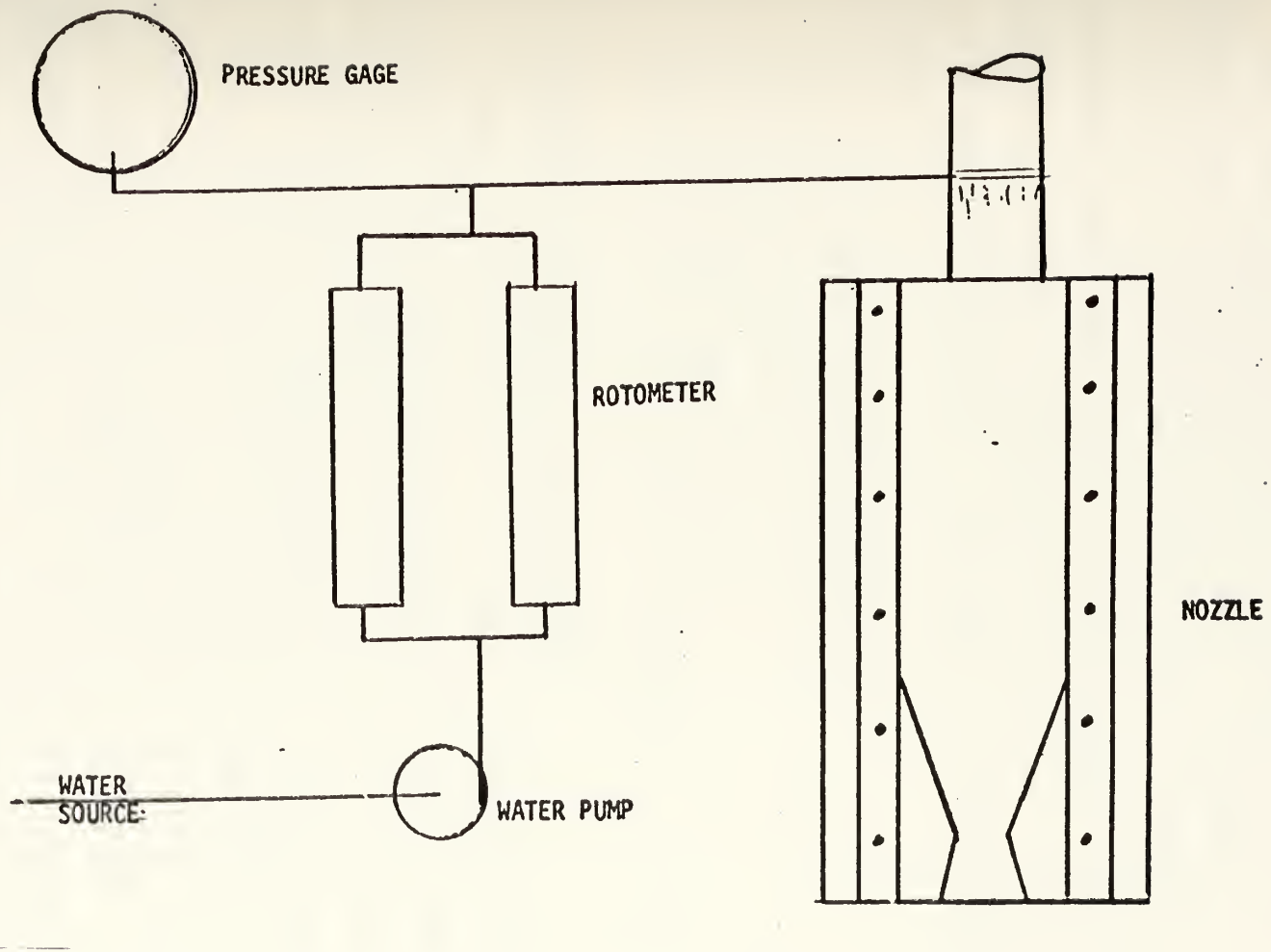


Figure 16. Liquid Injection System Schematic

V. INSTRUMENTATION SYSTEM

The instrumentation system is designed for automated data acquisition, analysis, and display. A schematic is depicted in Figure 17. Where ever possible, test operations and sequencing are under direct computer control. Each parameter measured involves an appropriate transducer, excitation source, and calibration procedure. The major instrumentation sub-systems are:

(A) Pressure Measuring Transducers

(B) Nozzle Thrust Force Block

(C) Flow Measurement Devices

(D) Data Acquisition/Control System

A. PRESSURE MEASURING TRANSDUCERS

Pressure measurements are made in fourteen locations throughout the experimental apparatus. Eleven Micro Switch 140PC pressure transducers model PK 87633 are placed on the nozzle assembly to measure pressure at various axial positions. Specifications for this model transducer are shown in Figure 18. The first pressure tap is located at one half inch from the inlet along the axis of the nozzle. The remainder are placed at one inch intervals toward the nozzle exit. These pressure taps are connected to the pressure transducers via a 1/4" o.d. plastic tubing. The

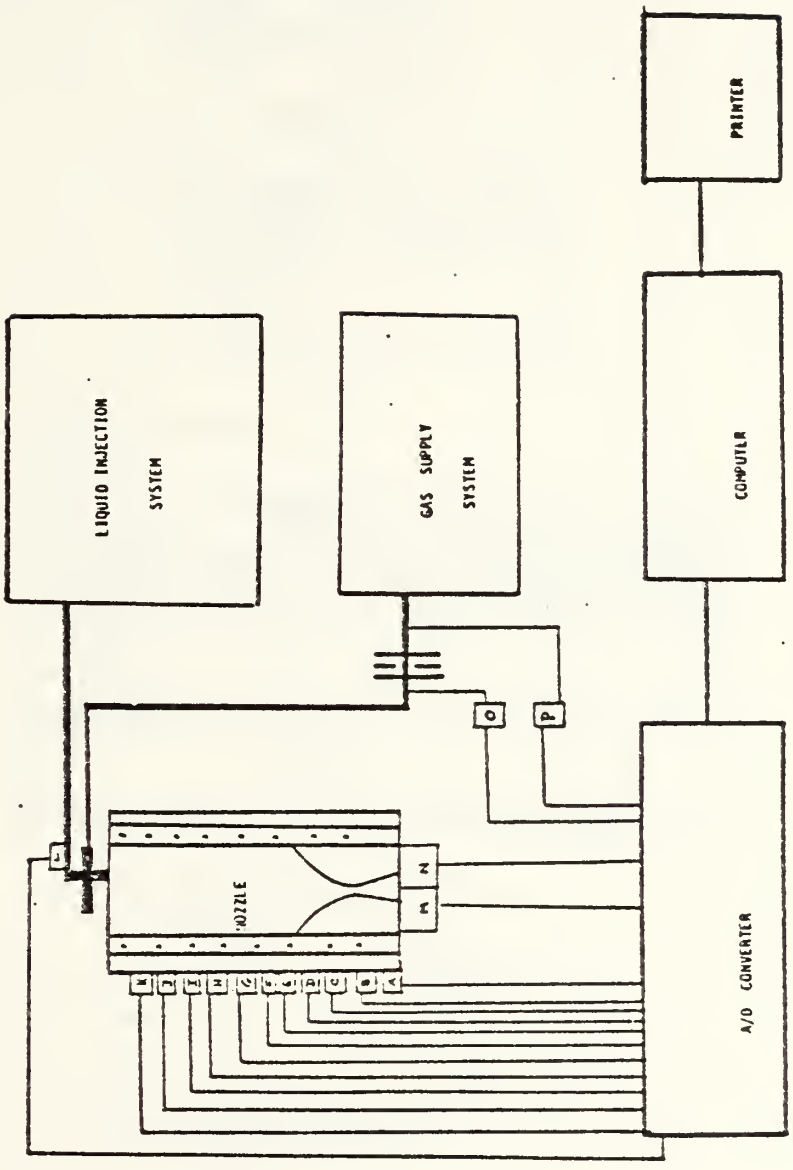
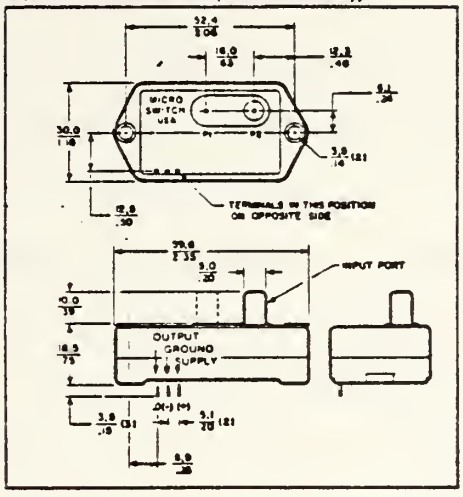


Figure 17. Instrumentation System Schematic

MOUNTING DIMENSIONS (for reference only)

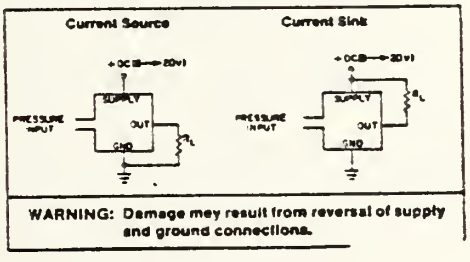


140PC SPECIFICATIONS at 8.0 0.01VDC, 25°C

ALL LISTINGS

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.85	5.00	5.15	Volts
Null Offset	All	0.95	1.00	1.05	Volts
Excitation	All	8.00		20.0	VDC
Output Current	All				
Source		10.0			mA
Sink		5.0			
Supply Current	All				
(10K ohm load)			8.0		mA
Overpressure	0-1			20	psi
	0-5			20	
	0-15			45	
	0-15/0-30(L)			60	
Operating Temperature		-55°C to +125°C(-65°F to +257°F)			

ELECTRICAL AND PRESSURE CONNECTIONS



WARNING: Damage may result from reversal of supply and ground connections.

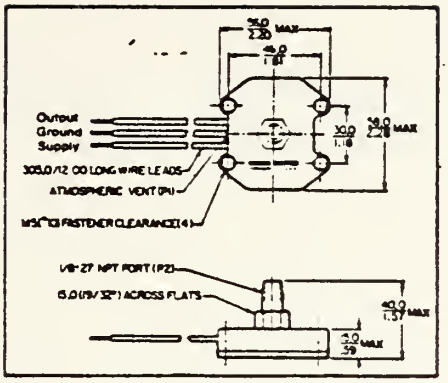
Figure 18. 140PC Pressure Transducer Specifications

pressure transducers are mounted on the side panel of the nozzle. See Figure 19 for locations. Each transducer has an identification letter corresponding to its position. Table I is the ID code for the transducers.

At the nozzle inlet a Micro Switch 200PC pressure transducer model PK 87690 is placed in the inlet line to measure the dual-phase mixture inlet pressure. Specifications for this model transducers are shown in Figure 19. Gas supply pressure is measured using a 200PC pressure transducer located at the orifice outlet. This transducer is also used to help measure differential pressure across the orifice. Another 200PC transducer is placed at the inlet of the orifice. The data acquisition program calculates the orifice differential pressure and then the air mass rate using the output from the above two transducers.

The pressure transducers provide output voltage proportional to applied pressure. These operate from a single, positive supply voltage ranging from 8 to 20 VDC. The supply voltage was maintained at 15VDC.

Each pressure transducer sends back a signal proportional to the input pressure. The signal is converted in the A/D converter to a digital signal which can be read by the HP9826. The pressure transducers were calibrated using a known pressure source. Appendix F depicts a sample calibration program written for a HP9826 computer. This program reads ten



200PC SPECIFICATIONS at 8.0 ± 0.01VDC, 25°C (unless otherwise noted)

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.80	5.00	5.20	V
Null Offset	All	0.95	1.00	1.05	V
Proof Pressure ①	0-100			200	psi
	0-250			500	
Burst Pressure ②	0-100		800		psi
	0-250		1000		
Excitation	All	8.0		20.0	VDC
Output Current	All				
Source		10.0			mA
Sink		5.0			
Supply Current	All		8.0		mA
Operating Tempature	All		-55°C to +125°C (-65°F to +257°F)		

*F.S.O. is the algebraic difference between end points (null and full pressure outputs).

① Maximum pressure without damage
② Without housing envelope rupture.

ELECTRICAL AND PRESSURE CONNECTIONS

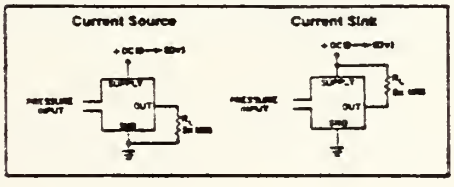


Figure 19. 200PC Pressure Transducer Specifications

Table I. ID Code for Instrumentation

Letter Designation	Description
A	10.5" from inlet
B	9.5" from inlet
C	8.5" from inlet
D	7.5" from inlet
E	6.5" from inlet
F	5.5" from inlet
G	4.5" from inlet
H	3.5" from inlet
I	2.5" from inlet
J	1.5" from inlet
K	0.5" from inlet
L	inlet nozzle pressure
M	force-block signal
N	force-block excitation voltage
O	orifice exit pressure
P	orifice inlet pressure

$$\text{Pressure} = A + B(\text{volts}) + C(\text{volts})^2 + D(\text{volts})^3$$

pressure transducer	A	B	C	D
A	-6.049	3.926	-.17336	.01121
B	-7.059	4.234	-.22921	.01415
C	-.6491	3.934	-.16025	.00945
D	-7.056	4.692	-.34118	.01898
E	-7.009	4.152	-.20717	.01237
F	-6.389	3.933	-.16055	.00951
G	-6.589	3.956	-.16427	.00961
H	-6.588	3.908	-.15806	.00942
I	-6.595	3.949	-.16270	.00957
J	-6.353	3.927	-.16509	.00998
K	-6.203	3.846	-.14697	.00880
L	-20.207	11.157	-.08591	.00492
O	-20.668	11.068	-.07562	.01118
P	-18.827	11.928	-.17715	.01101

Figure 20. List of Polynomial Coefficients for Pressure Transducer

values of pressure for each 140PC transducer and gives the mean and standard deviation for each from 0 to 45 psi in 5 psi increments. Appendix G depicts sample output of the program for a given pressure. Appendix H illustrates the program used to calibrate the 200PC pressure transducers. The program works as above, except values are taken from 0 to 60 psi at 5 psi increments.

Data obtained during calibration source pressure is plotted for each pressure transducer (Appendix I). Each plot was curve fitted with a third order polynomial. Figure 20 shows coefficients of the polynomial. These polynomials are used in the data acquisition/control program to convert transducer readings to pressure readings.

B. NOZZLE THRUST FORCE-BLOCK

The thrust produced by the nozzle was employed to deduce the nozzle exit velocities. The thrust was measured by instrumenting a target plate in the exit flow field. Appropriate screens were installed to prevent liquid "bounce back." The jet momentum force on the target is acquired by a balance beam system shown in Figure 21. A Kistler-Morse force block provides an analog signal proportional to the nozzle jet momentum.

The calibration of the force-block was completed by placing known weights on the force-block side of the balance

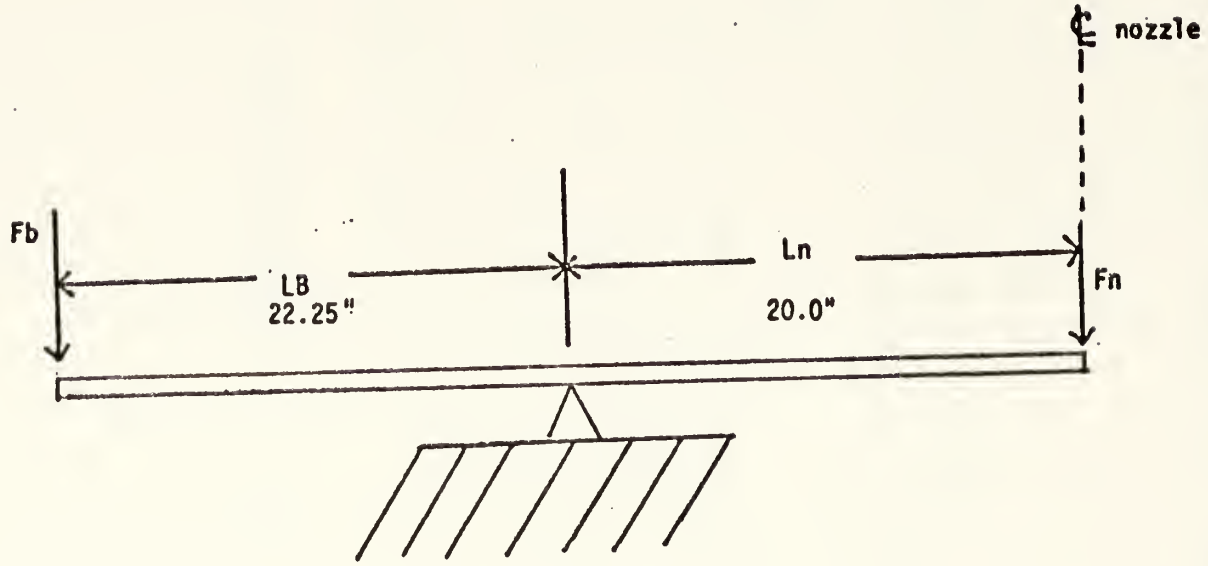


Figure 21. Force-Block Balance Beam Diagram

beam, (Figure 21), and recording the voltage produced. Appendix J shows results of this calibration. These results were curve fitted with a third order polynomial. The following is the volt-to-force conversion polynomial:

FB = (1/453.6)*(-234.396+48715.28*VOLTS-11261.54*VOLTS+33899.3*VOLTS)

FN = FB*LB/LN

FN = FORCE AT NOZZLE EXIT (LBF)

FB = FORCE AT FORCE BLOCK (LBS)

LB = LENGTH FROM PIVOT TO FORCE BLOCK(IN.)

LN = LENGTH FROM PIVOT TO DIRECTIONAL OBSTRUCTION(IN.)

C. FLOW MEASUREMENT

1. Air mass flow measurement for the system achieved by measuring the inlet and outlet pressure on a D-10512 orifice with a 0.92 inch bore. For details on orifice see Section III. Air flow is calculated in the data acquisition program. The program uses the following equation obtained from References 4 and 5.

$$M_{air} = K A_2 Y\sqrt{2G_c \rho_1(P1-P2)} \quad \text{where}$$

K = CE

$E = {}^{1}/_{(1-B^4)^{1/2}}$

$\beta = d/D$

C = 0.60

A_2 = AREA OF ORIFICE = $\frac{\pi D^2}{4}$ FT2

G_c = 32.2 FT/SEC2

ρ_1 = DENSITY LBM/FT3

P1 = PRESSURE AT INLET IN LBF/FT2

P2 = PRESSURE AT LUTLET IN LBF/FT2

M_{air} = AIR MASS FLOW RATE LBM/SEC

The discharge coefficient C is the factor that accounts for losses through the orifice. Since the values of C varies from .62 to .60 for R_d number from 10^4 to 10^7 with β = .3, C will be considered constant.

2. Water flow measurement was made using two rotometers. Calibration of the rotometers were made by measuring the time for a given weight of fluid flow. The mass flow rate was calculated and plotted versus the rotometer reading. Appendix K is the plot of the results. The plot was curve fitted with a third order polynomial. The following is that polynomial:

MH20 = -.0063268+.002097278*RR-.00000658*RR^2+1.1X10*RR^2

where RR = rotometer reading

D. DATA ACQUISITION/CONTROL SYSTEM

The heart of the data acquisition system is a HP9826 small computer. The HP9826 communicates via a Hewlett Packard 3497A data acquisition/control system. This system gathers data from the pressure transducers and nozzle thrust force-block. It converts the analog signal to digital data, and stores the data in memory. Figure 22 shows a pressure transducer to A/D converter channel connection, and Figure 23

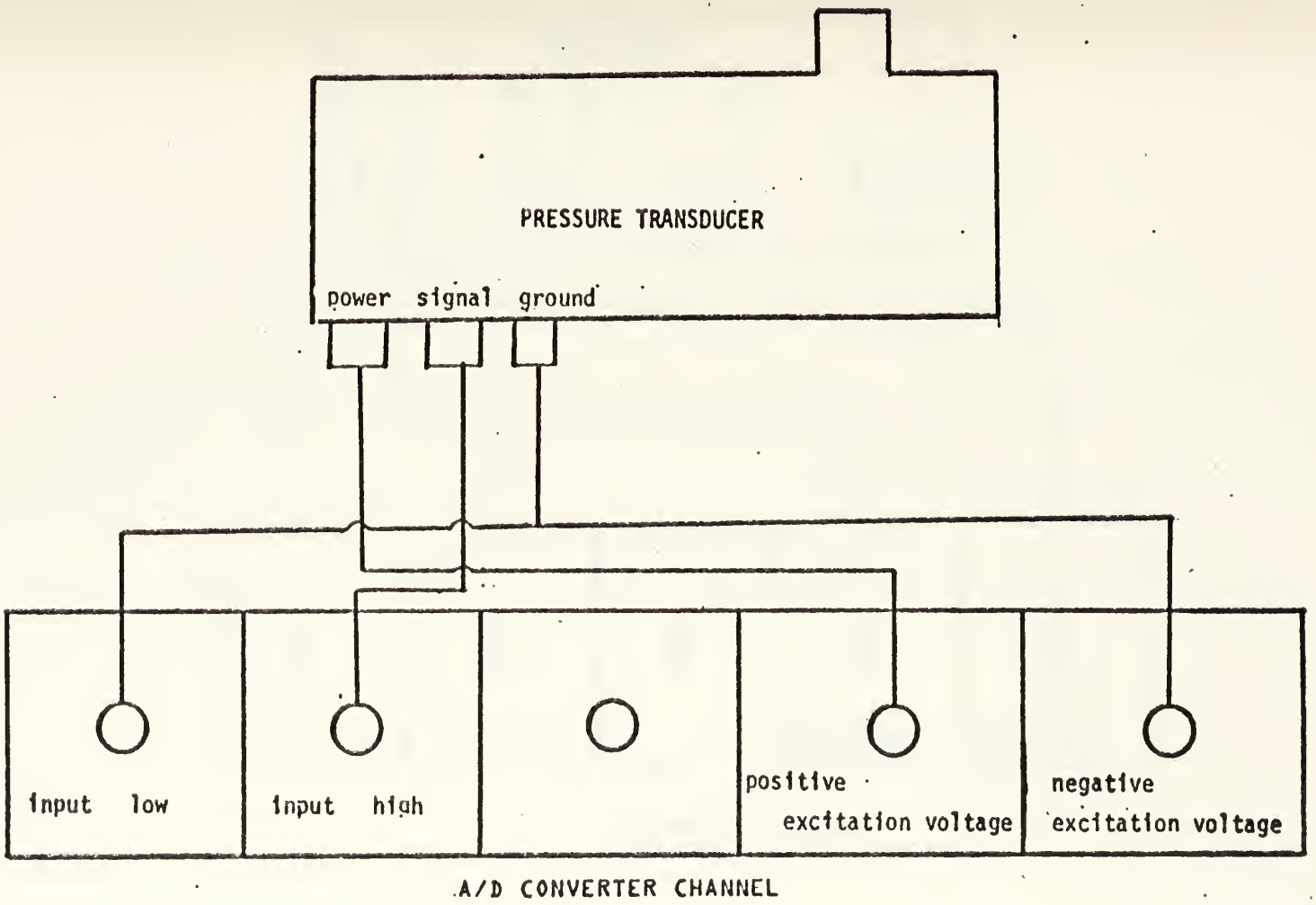


Figure 22. Transducer-to-Channel Connection

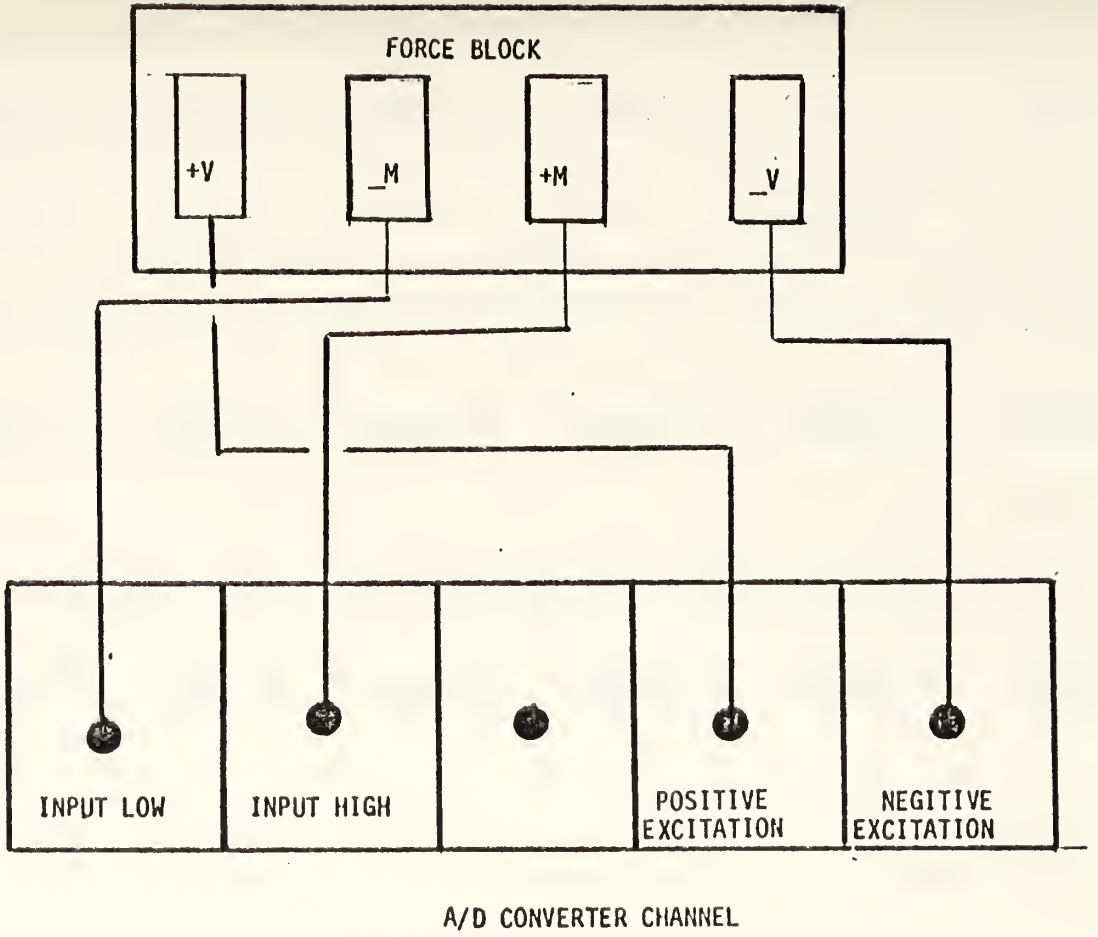


Figure 23. Force-Block-to-Channel Connection

CHANNEL 7	CHANNEL 8	CHANNEL 9	CHANNEL 16	CHANNEL 17	CHANNEL 18
G	H	I		EXCITATION VOLTAGE	

CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 13	CHANNEL 14	CHANNEL 15
D	E	F	O	P	M,N

CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 10	CHANNEL 11	CHANNEL 12
A	B	C	J	K	L

BUS CONNECTION TO A/D CONVERTER

Figure 24. Bus Connection-to-A/D Converter Connections

the force-block to A/D converter channel connection. Figure 24 depicts the current connection to the data acquisition/ control system bus from the sensors.

The data acquisition and analysis program is a fully automated system which integrates the use of the HP9826, HP3497A, and all sensor devices. The program can be divided into three sections:

1. Data Acquisition - Data is acquired from 15 different sensor devices. All system parameters are initialized and configuration types are inputted into the computer memory for future use. Ten readings are made on each sensor and a mean value for each is calculated and stored in memory.
2. Data Conversion - Input data conversion is completed by using calibration information obtained on each pressure transducer and force-block. The program takes the stored mean values from memory, and converts the input voltage to a pressure or force using the third order calibration polynomial for each sensor.
3. Data Analysis - This is the heart of the program in that all performance parameters are calculated and printed. It uses all of the above information to calculate mass flow rate of water, mass flow rate of air, total mass flow rate, thrust, mixture

ratio, exit velocity and all pressure information. The following equations are also used:

Exit Velocity = (Thrust/Total Mass Flow Rate)* g_c(ft/sec)

Mixture Ratio = $\dot{m}_{water}/\dot{m}_{air}$

Total Mass Flow Rate = $\dot{m}_{water} + \dot{m}_{air}$ $(\frac{lbm}{sec})$

Appendix L is the data acquisition program and sample output.

VI. EXPERIMENTAL RESULTS

Six test runs were made using the equipment described in the previous sections. It was found that the inlet pressure to the nozzle remained nearly constant for each setting. The testing was conducted by maintaining a constant air control valve setting and varying the mass flow rate of water. The regulator outlet pressure of the nitrogen bottle which controls the air valve was set at 30 psi and 15 psi. These settings correspond to nozzle inlet pressure of 35 $\pm$ 1.0 psi and 29 $\pm$ 1.0 psi respectively. For each nozzle inlet pressure, experimental data was obtained at varying mass ratios of water-to-air in the range of 2 to 13. These experiments were conducted with three discharge area ratios (A_{inlet}/A_{out}). Those ratios are: 3.586, 2.600, and 1.9259. The results of the six experimental tests are displayed in Tables II through VII.

Inlet air was limited to a maximum value of 40 psi. The 140PC pressure transducer's maximum output pressure is 40 psi, (see information on 140PC transducer Figure 21). The experimental system has the ability to reach higher pressures. The present configuration may be operated to 70 psig.

Table II. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN********PRESSURE 29.00000 PSI

MASS FLOW RATE			MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
TOTAL	AIR	WATER				
0.06050	0.01830	0.04220	2.30000	1998.00000	1950.39900	3.75000
0.10150	0.01840	0.08346	4.62000	1243.30000	1300.00000	3.92000
0.13650	0.01790	0.11860	6.64000	969.69990	1001.89900	4.11000
0.16630	0.01770	0.14860	8.39000	806.10000	830.60000	4.16000
0.19220	0.01770	0.17450	9.83000	710.69990	760.30000	4.24000
0.21490	0.01750	0.19730	11.26000	643.19990	695.50000	4.29000
0.23580	0.01750	0.21810	12.39000	602.50000	642.00000	4.41000
0.25550	0.01760	0.23790	13.51000	550.00000	620.89990	4.37000

Table III. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN********PRESSURE 35.00000 PSI

MASS FLOW RATE			MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
TOTAL	AIR	WATER				
0.06300	0.02080	0.04220	2.02000	2440.50000	2430.30000	4.77000
0.10410	0.02060	0.08346	4.05000	1536.10000	1611.50000	4.97000
0.13890	0.02030	0.11860	5.85000	1192.19900	1240.69900	5.14000
0.16840	0.01980	0.14860	7.50000	1007.30000	1031.30000	5.27000
0.19450	0.02000	0.17450	8.73000	880.83000	930.80000	5.32000
0.21720	0.01990	0.19730	9.93000	810.60000	860.75000	5.47000
0.23820	0.02000	0.21810	10.89000	735.69990	810.50000	5.44000
0.25750	0.01950	0.23790	12.18900	669.19990	715.30000	5.34000

Table IV. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.62500 SQ.IN********PRESSURE 29.00000 PSI

MASS FLOW RATE			MASS	EXPERIMENTAL EXIT	REAL EXIT	
TOTAL	AIR	WATER	RATIO	VELOCITY	VELOCITY	THRUST
0.06040	0.01820	0.04220	2.32000	1834.50000	1880.30000	3.44000
0.10150	0.01810	0.08346	4.61000	1158.00000	1201.19900	3.66000
0.13660	0.01800	0.11860	6.59000	937.80000	953.60000	3.98000
0.16650	0.01790	0.14860	8.32000	802.19990	803.10000	4.15000
0.19220	0.01770	0.17450	9.85000	688.60000	749.19990	4.21000
0.21510	0.01780	0.19730	11.10000	643.19990	702.10000	4.30000
0.23550	0.01740	0.21810	12.60000	589.89990	670.10000	4.32000

Table V. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.62500 SQ.IN********PRESSURE 35.00000 PSI

MASS FLOW RATE			MASS	EXPERIMENTAL REAL EXIT VELOCITY		
TOTAL	AIR	WATER	RATIO	EXIT VELOCITY		THRUST
0.09370	0.02900	0.04220	2.02000	2165.89900	2210.30000	4.24000
0.13910	0.02050	0.11860	5.77000	1097.10000	1153.10000	4.74000
0.16900	0.02050	0.14860	7.27000	940.50000	998.39990	4.94000
0.19980	0.02030	0.17450	8.60000	832.89990	885.30000	5.04000
0.21760	0.02030	0.19730	9.72000	765.39990	801.60000	5.17000
0.23820	0.02010	0.21810	10.87000	720.50000	753.39990	5.32000
0.25770	0.01890	0.23790	12.03000	674.80000	700.30000	5.40000

Table VI. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.84375 SQ.IN********PRESSURE 29.00000 PSI

MASS FLOW RATE			MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
TOTAL	AIR	WATER				
0.06110	0.01890	0.04220	2.23000	1586.69900	1653.39900	3.01000
0.10210	0.01860	0.08346	4.48000	1069.10000	1101.60000	3.39000
0.13700	0.01840	0.11860	6.44000	850.39990	900.89990	3.61000
0.16680	0.01820	0.14860	8.19000	754.69990	791.10000	3.91000
0.19250	0.01800	0.17450	9.69000	655.60000	720.10000	3.92000
0.21560	0.01820	0.19730	10.84000	596.80000	675.30000	3.99000
0.23610	0.01800	0.21810	12.14000	576.10000	638.19990	4.22000
0.25560	0.01770	0.23790	13.46000	570.50000	610.50000	4.52000

Table VII. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.84375 SQ.IN********PRESSURE 35.00000 PSI

MASS FLOW RATE			MASS	EXPERIMENTAL EXIT	REAL EXIT	
TOTAL	AIR	WATER	RATIO	VELOCITY	VELOCITY	THRUST
0.06350	0.02130	0.04220	1.98000	1727.39900	1807.60000	3.40000
0.10440	0.02090	0.08346	3.99000	1081.50000	1102.30000	3.50000
0.13900	0.02040	0.11860	5.82000	891.12980	913.80000	3.85000
0.16890	0.02030	0.14860	7.31000	721.50000	810.39990	3.78000
0.19460	0.02010	0.17450	8.70000	691.89990	741.10000	4.18000
0.21690	0.01960	0.19730	10.10000	604.19990	675.19990	4.07000
0.23810	0.02000	0.21810	10.90000	583.50000	660.00000	4.35000
0.25780	0.01980	0.23790	12.00000	516.96990	654.39990	4.42000

VII. DISCUSSION

The results of this investigation are in two parts; the experimental test results and the computer outputs based on initial conditions similar to those of the experiments.

The key variables are: the nozzle overall area ratio A_R, liquid/air mass flow ratio, nozzle exit velocity, nozzle supply pressure, nozzle thrust, and the nozzle axial pressure profiles. Figures 25 through 34 present the exit velocity vs. mass ratio results for the experiment and computer output. Figure 29-34 illustrates the comparison of the experimental results and the corresponding computer output. Figure 35 illustrates the variation of nozzle thrust with mass ratio for different area ratios and inlet pressures. Figures 36 and 37 present the axial pressure profiles.

In all cases the exit plane velocity decreases as the liquid/air mass ratio is increased. In the low mass ratio range (i.e., less than $\simeq$ 5) the velocity decrease is very pronounced. Past a mass ratio value of $\simeq$ 10 the velocity of the mixture becomes relatively insensitive to the mixture ratio. This is as would be expected. For the same inlet conditions there is a fixed amount of energy available for conversion to its kinetic form. In the nozzle process the energy is conserved and thus an increasing mass ratio is

manifested in a decreasing exit plane velocity. In all cases the agreement between the experimental tests and the analytic predictions are with in ≃ 10%.

There also was apparent and a consistent trend with respect to the nozzle area ratio and the exit velocity. As the nozzle exit area was increased the exit velocity of the mixture decreased. The effect seems to be more pronounced at the lower mass ratios. This trend was confirmed by observations of the actual flow field in the nozzle. If the exit area was increased significantly (beyond the max area used in those tests) there was evident an abrupt and severe separation within the diverging portion of the nozzle passage. This was accompanied by a drastic decrease in exit velocity as evidenced by the output from the thrust target. It appears that the diverging portion of the nozzle, at a certain point, starts to behave as a subsonic diffuser and hence experiences an adverse pressure gradient. This reasoning is in part confirmed by the pressure profiles identified in Figures 36 and 37.

The relationship between measured thrust and mass ratio (Figure 35) indicates a slightly increasing trend. This may be explained by considering the following. Each set of data points (at constant inlet air pressure and constant nozzle exit area) is developed by varying the mass ratio. This, in turn, is achieved by increasing the liquid rate by increasing the liquid supply pressure. The net result is an

increase in the liquid inlet velocity or an increase in the inlet energy level. Thus a particular data set is not truly at a constant inlet energy level but is increasing.

Perhaps the major discrepancy between the experimental test results and the computer analytic model is evidenced in the axial pressure profiles of Figures 36 and 37. It is clearly evident that at a certain point the nozzle passage reverts from a nozzle to a diffuser. This transition point occurs slightly downstream of the throat and the pressure starts to increase.

Unfortunately the computer analytic model requires a pressure profile as an input. Furthermore the pressure profile must be continuously decreasing. Thus the profile as obtained from the experiment are not directly useable. The situation is examined with the aid of Figure 38. Curve A is a typical axial pressure distribution as obtained from the experiment. Curve B is a pressure distribution used by Elliott in the application of his computer program. Pressure profiles C and D were arbitrarily defined and the exit plane velocity for each was calculated. Velocity variation in the range of 1% is evident. It appears that the final exit velocity is relatively insensitive to the actual pressure profile in the nozzle.

In light of the preceeding difficulty of matching the experimental pressure profile to the computer model and the

apparent flexibility of the type of pressure profile it was decided to employ a form of profile D of Figure 38. Thus instead of using the actual experimental pressure data as an input in the computer model, a profile resembling curve D was developed for each inlet pressure case.

It is apparent that within certain rather wide limits the Elliott computer model yields results that correspond within 10% to results obtained from the experiment. The general trends have been confirmed and their behavior has revealed nothing unexpected. The conclusion of Elliott [Ref. 1] has been largely substantiated. "It is very difficult to design a bad or a good dual-phase nozzle."

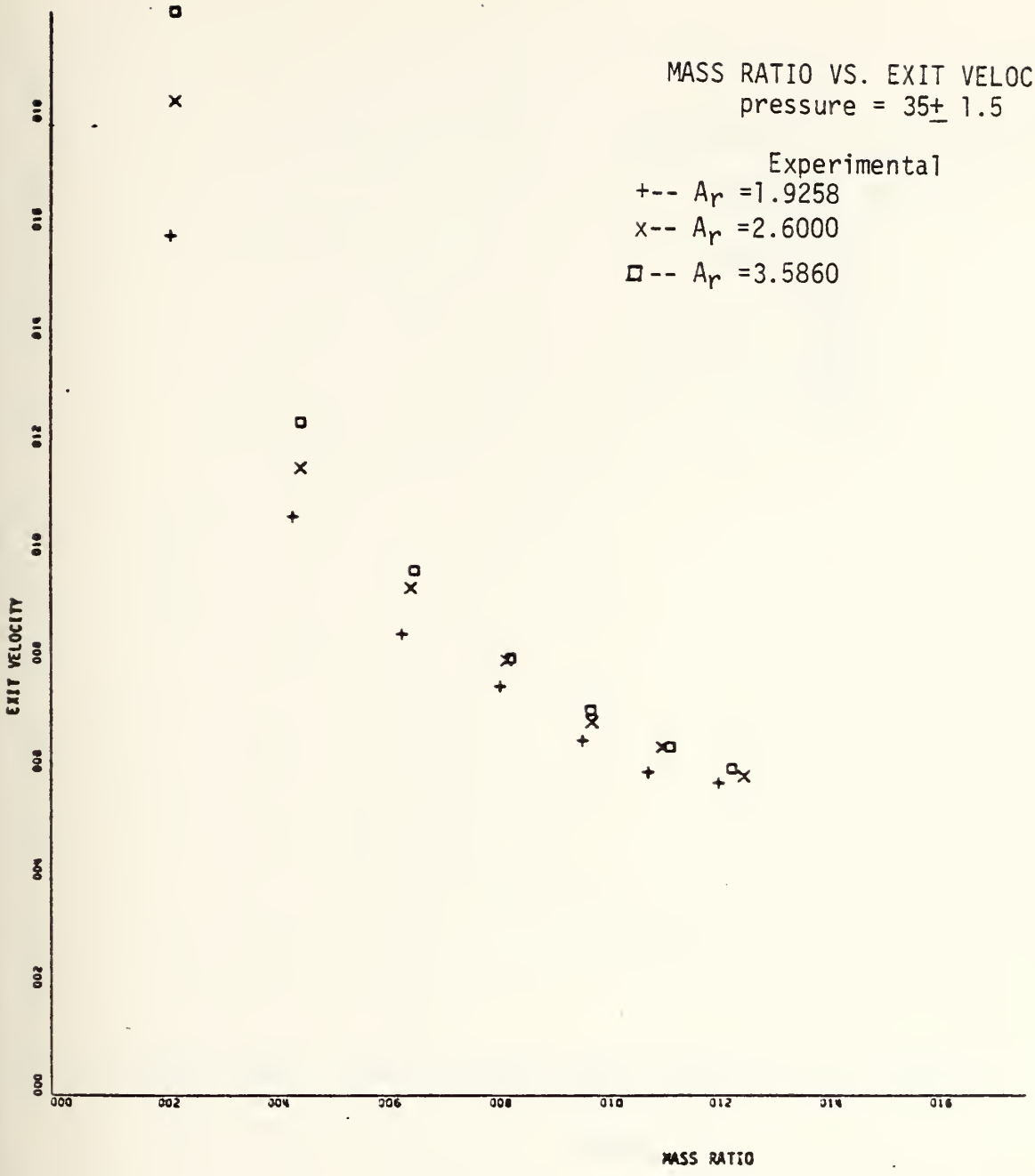
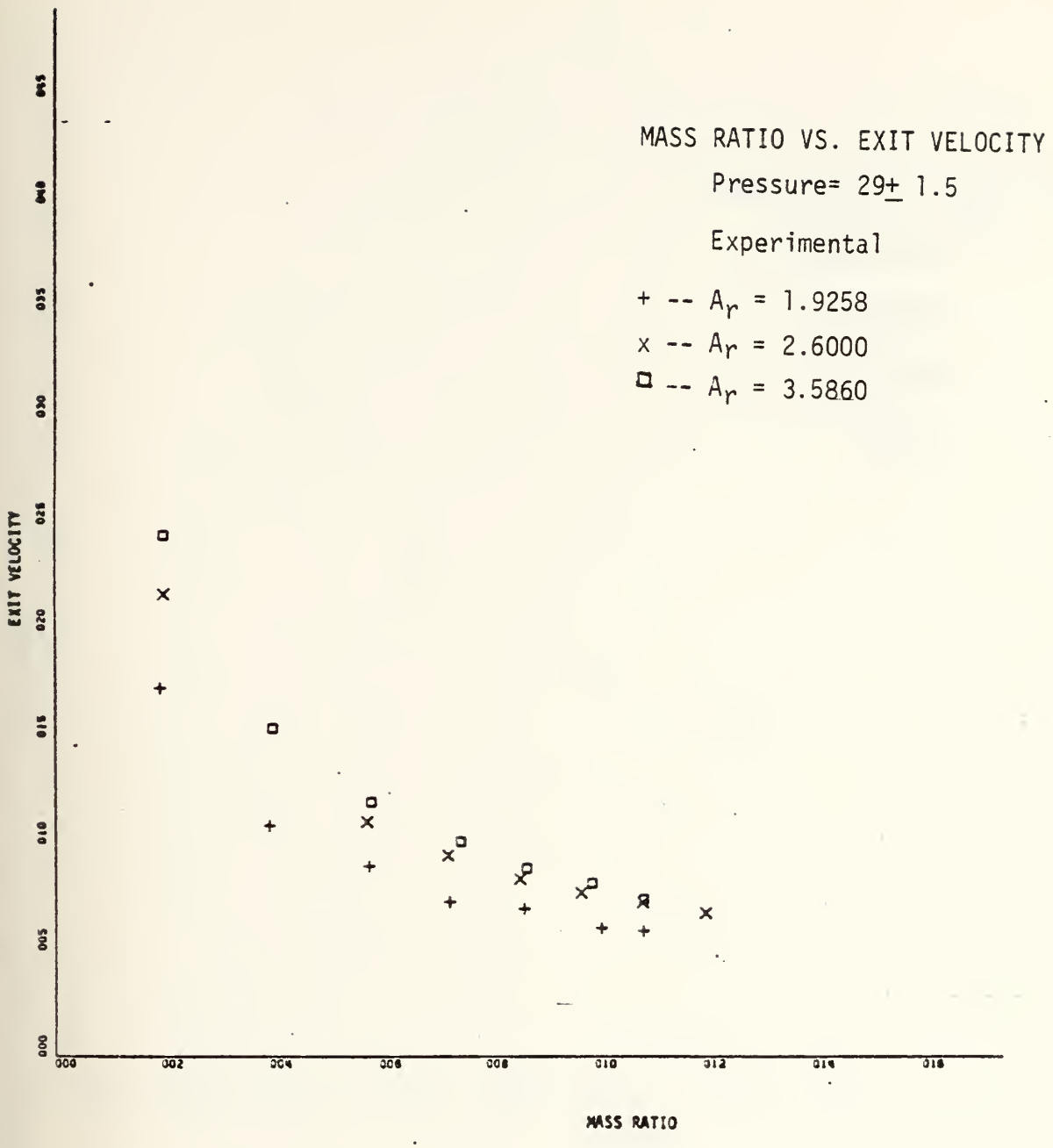
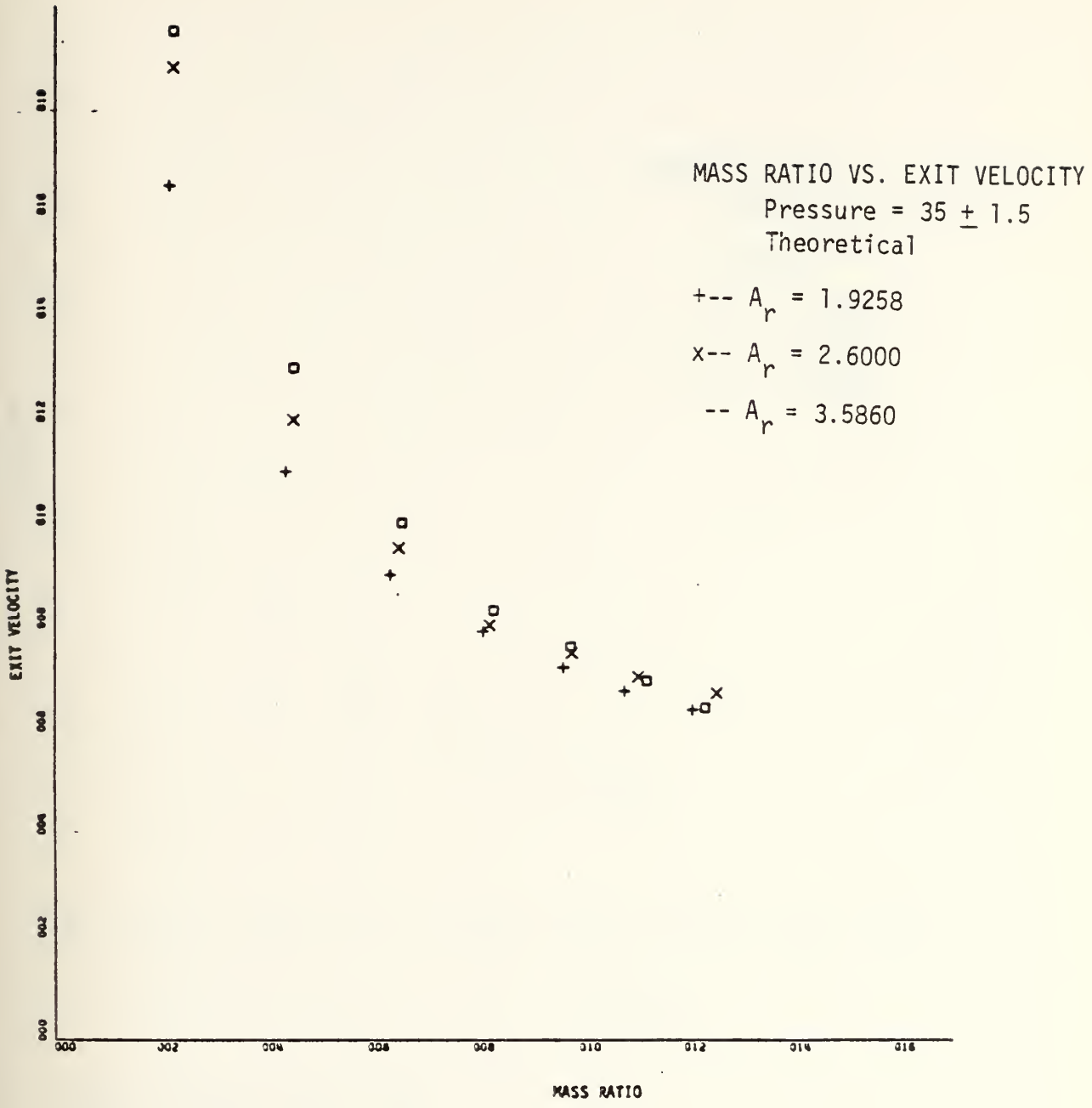


Figure 25. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Experimental



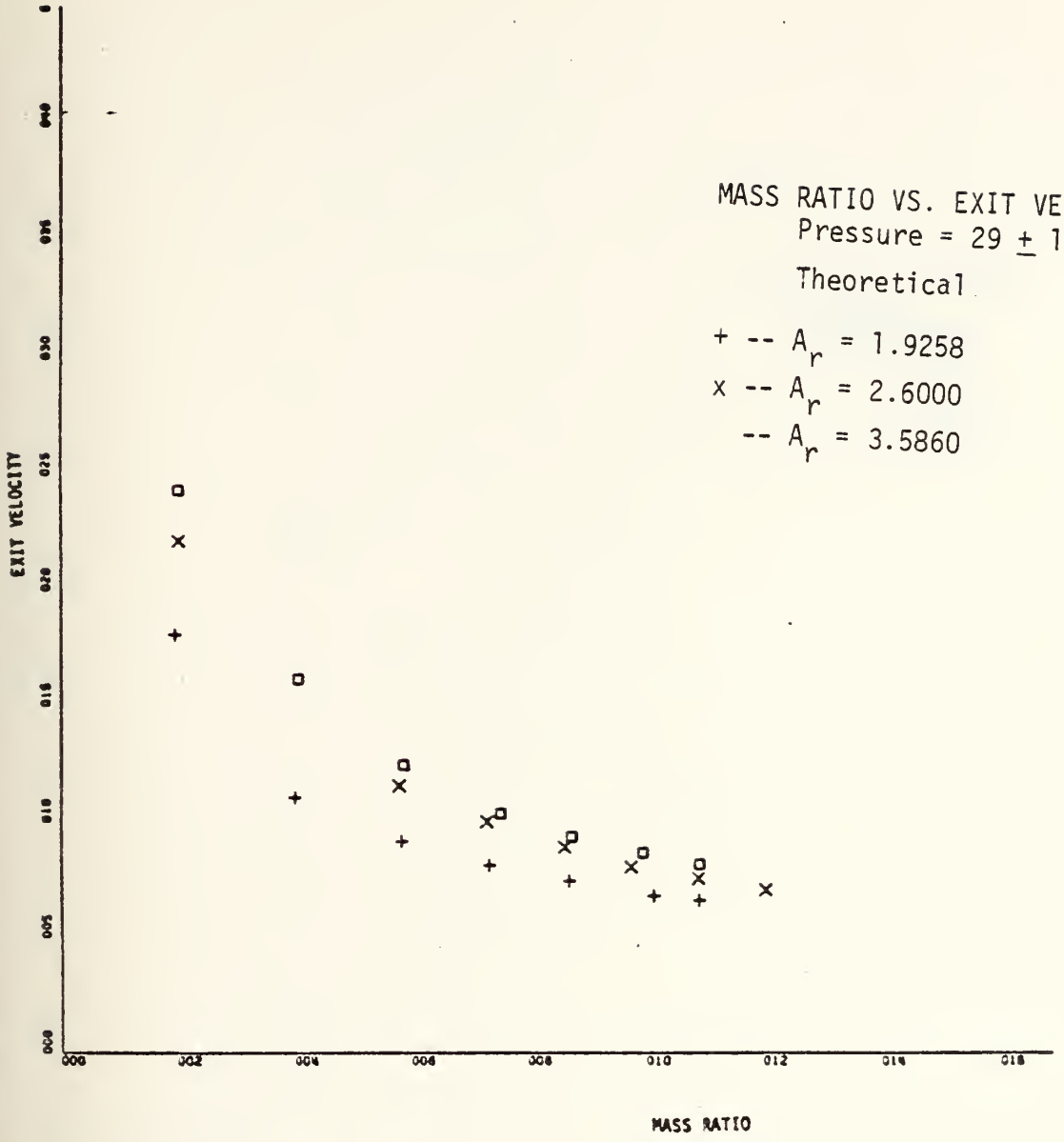
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 26. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Experimental



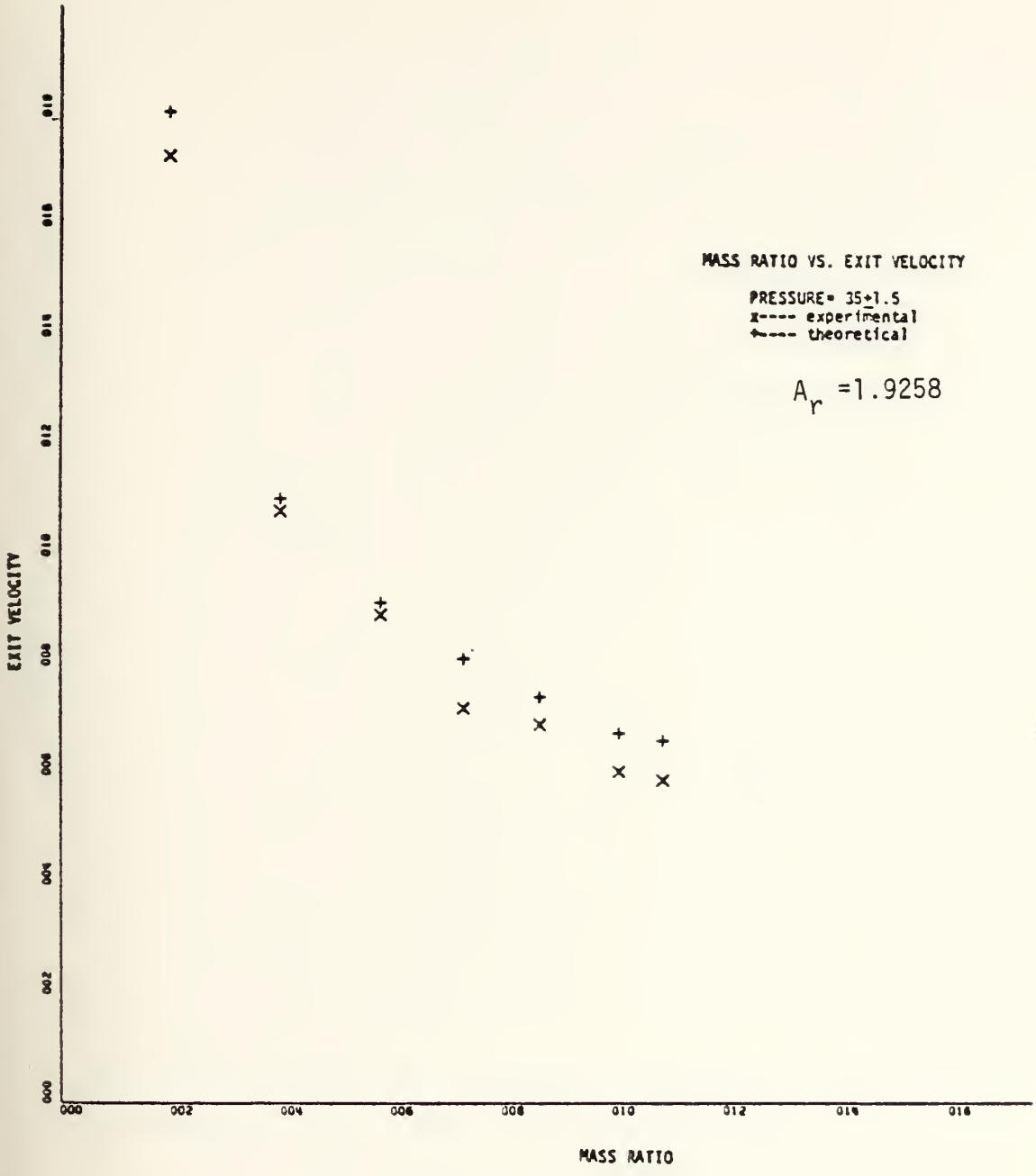
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 27. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Theoretical



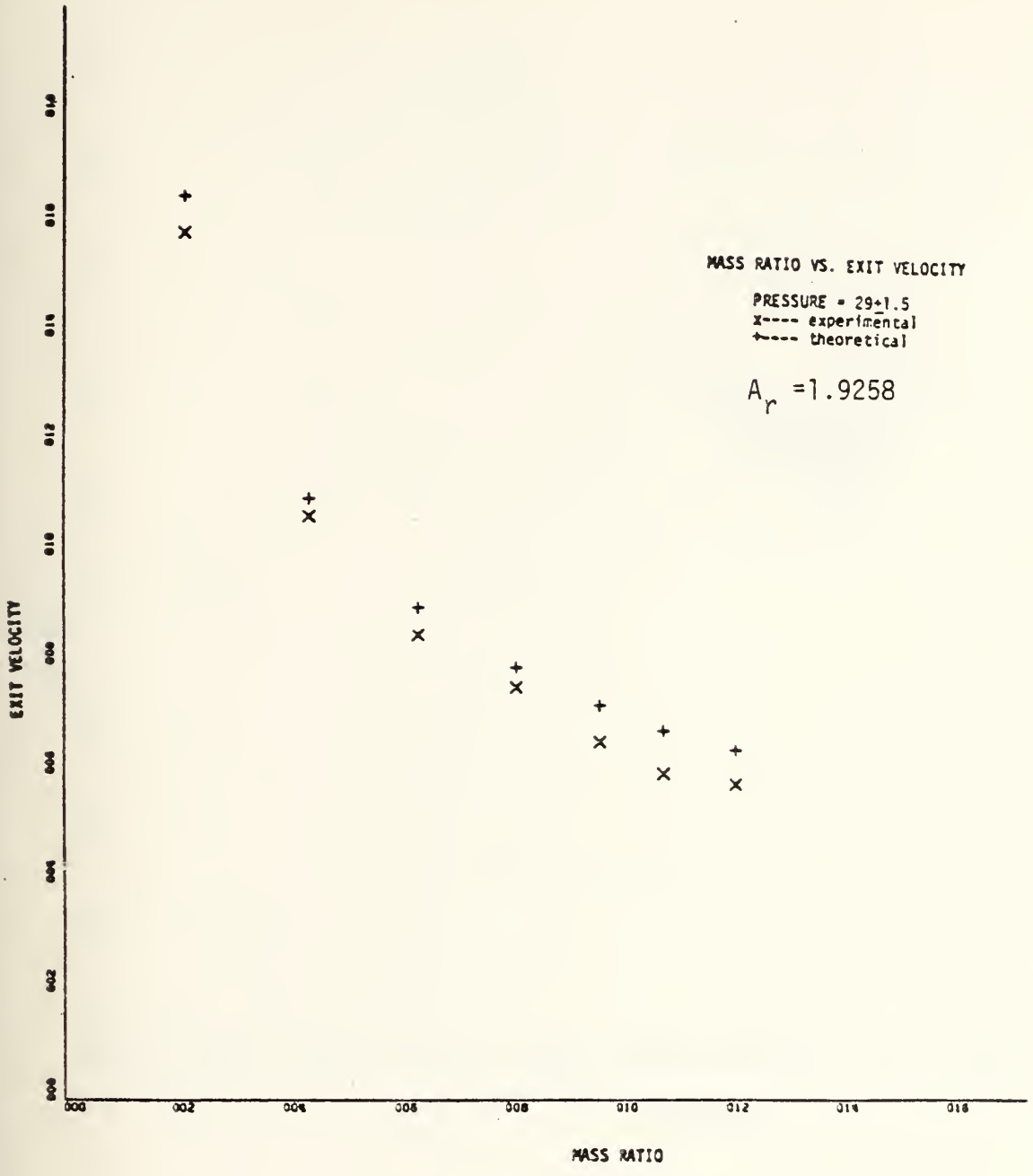
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 28. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Theoretical



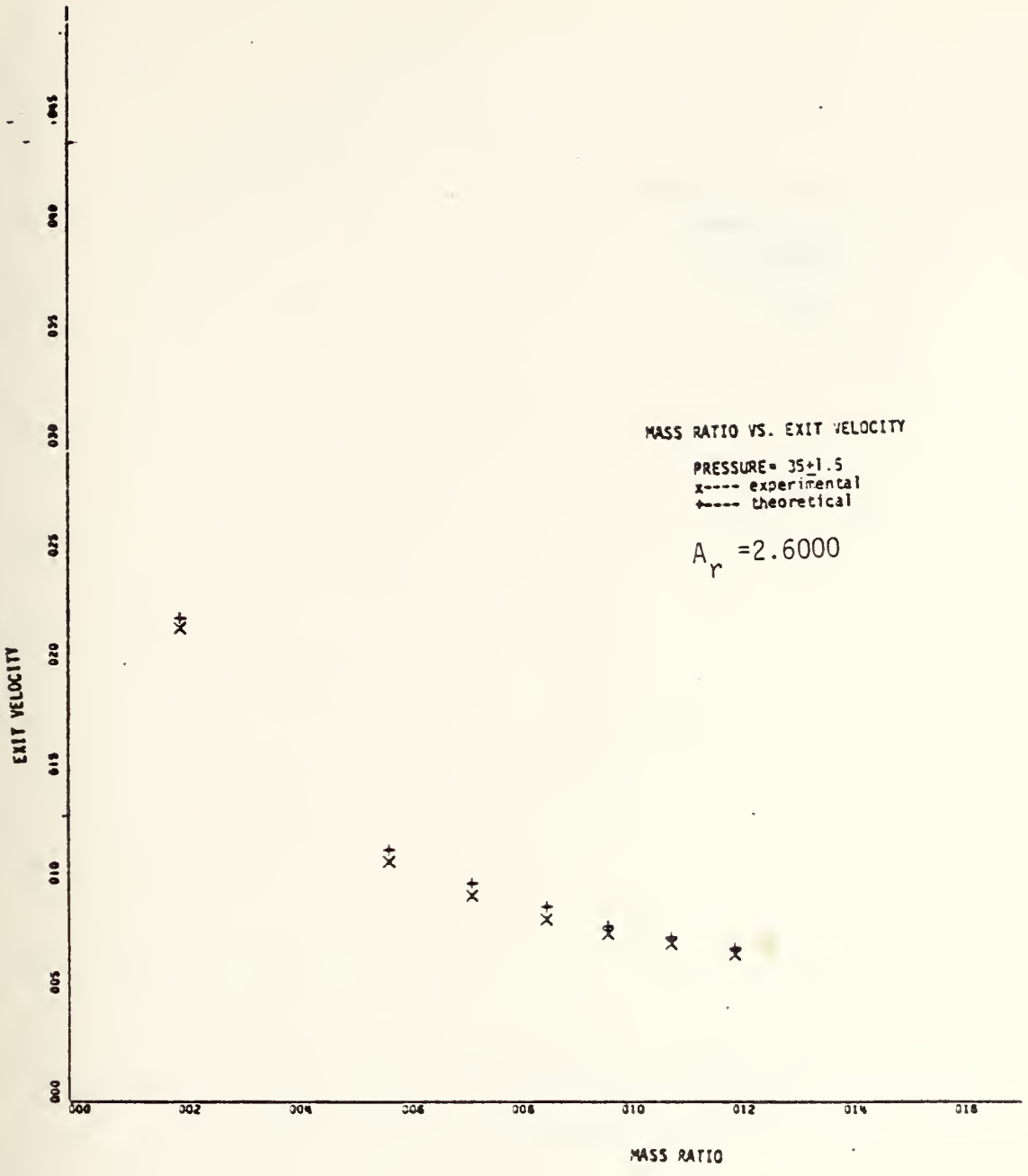
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 29. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .84375



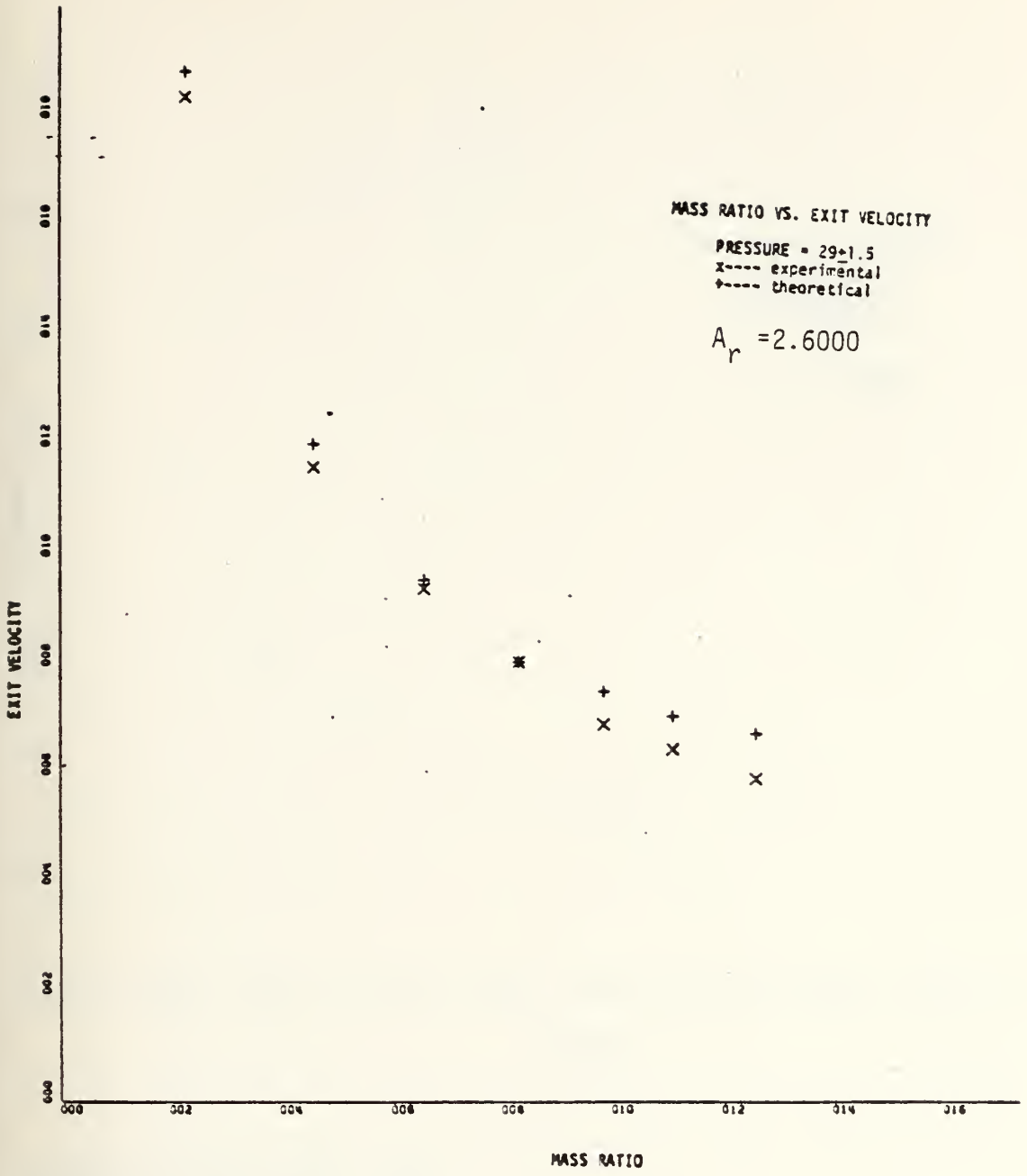
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 30. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .84375



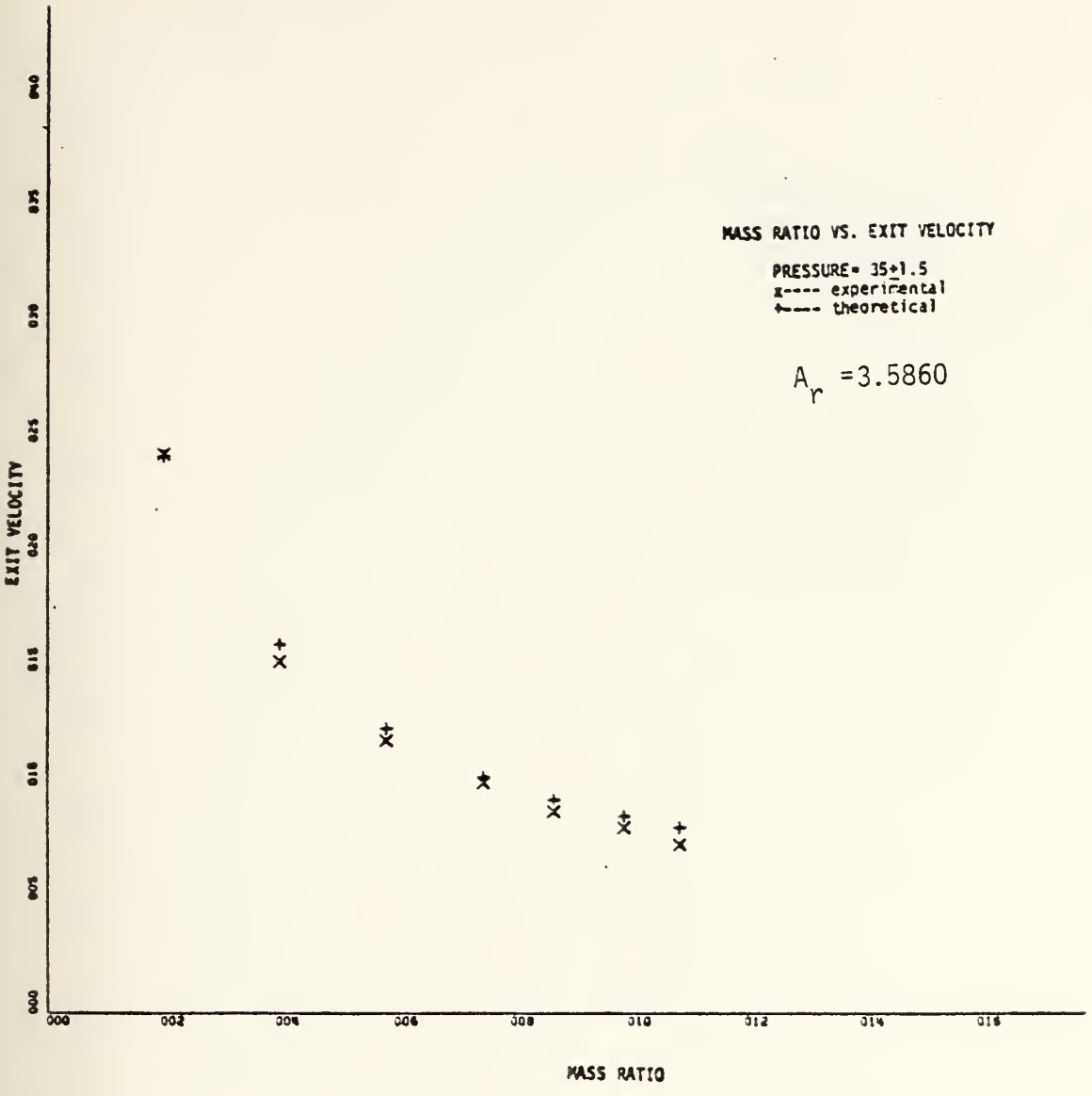
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 31. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .62500



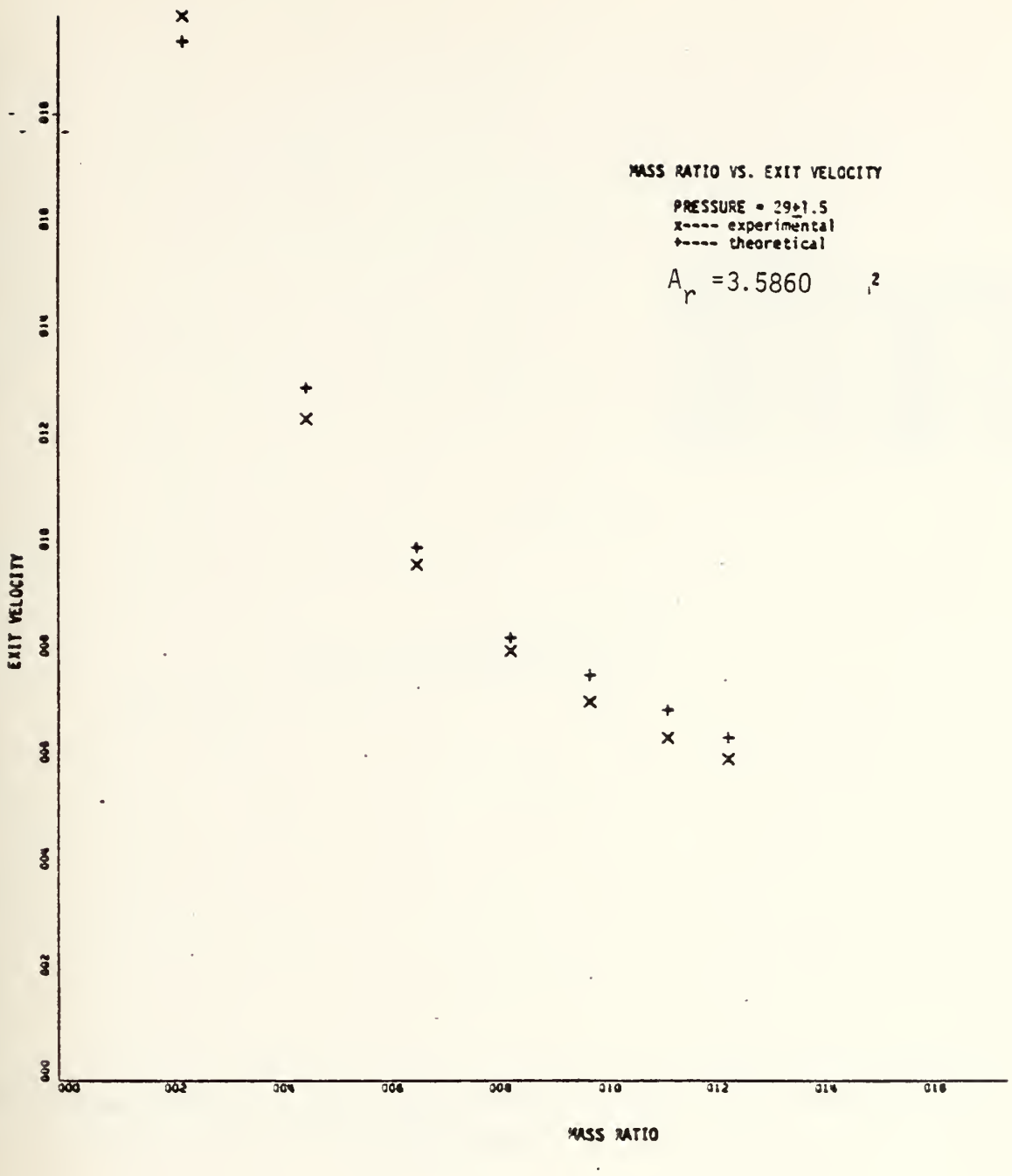
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 32. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .62500



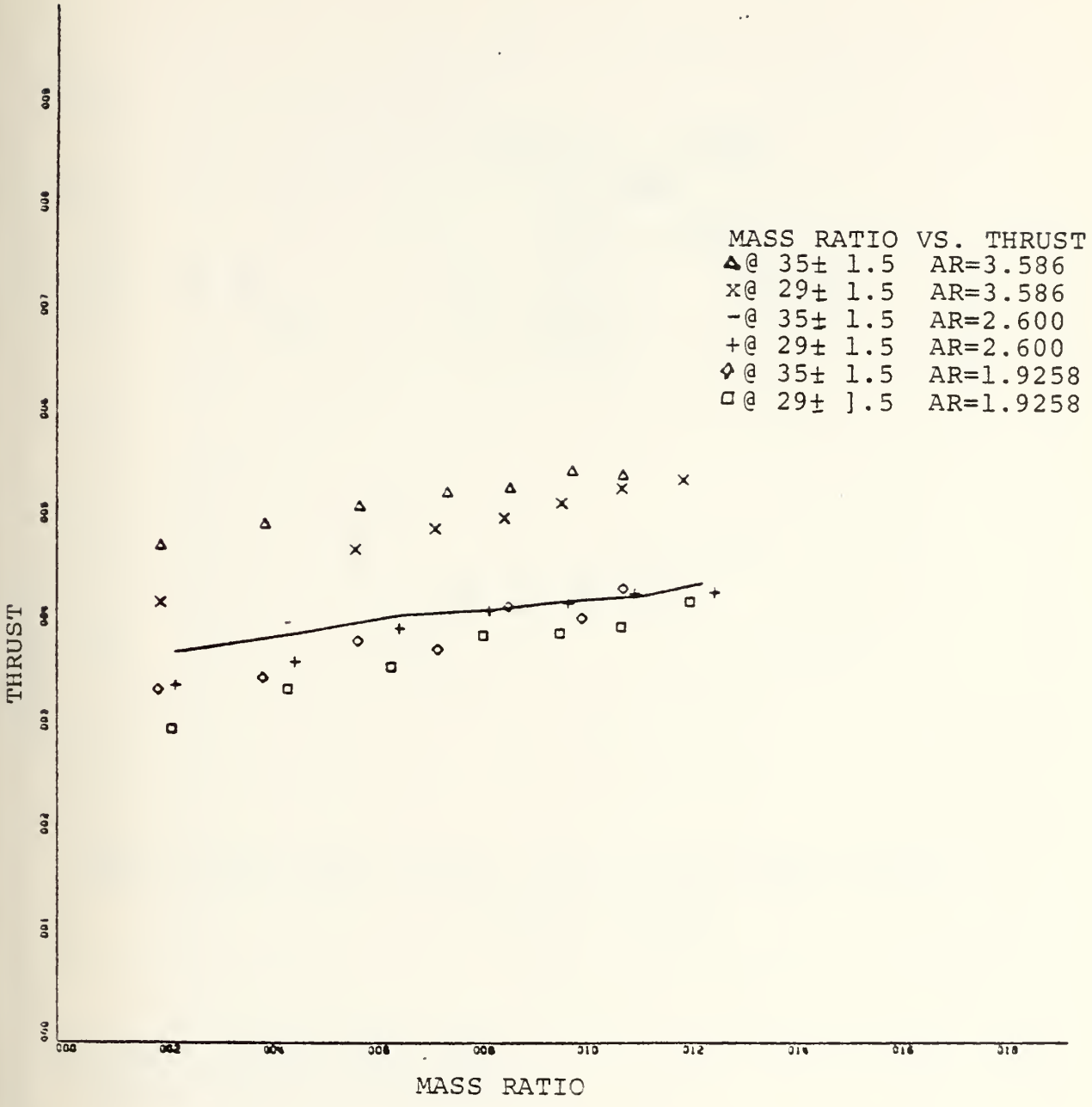
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 33. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .45313



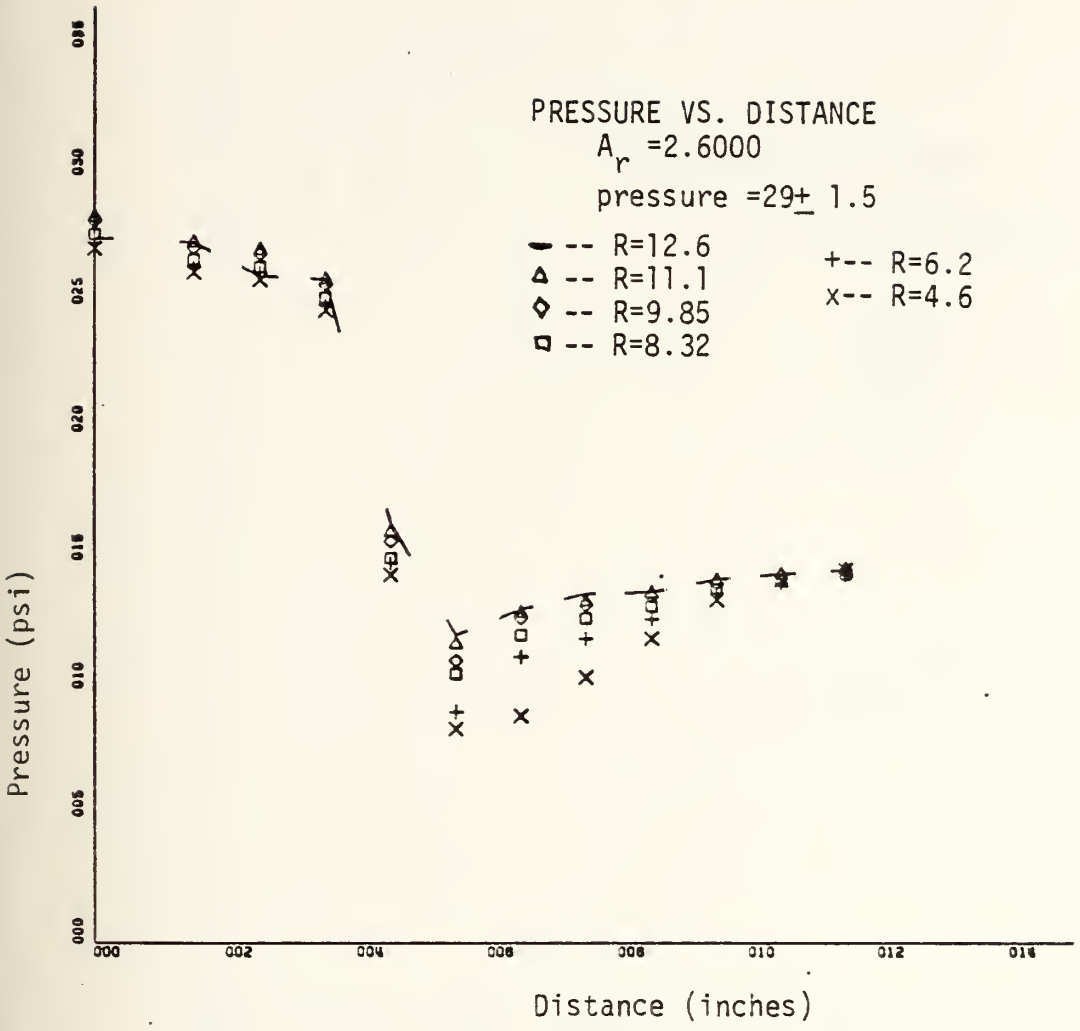
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 34. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .45313



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=1.00E+00 UNITS INCH.

Figure 35. Mass Ratio vs. Thrust Curve



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+00 UNITS INCH.

Figure 36. Pressure vs. Distance at Pressure = 29±1.5 Exit Area = .625 sq. in.

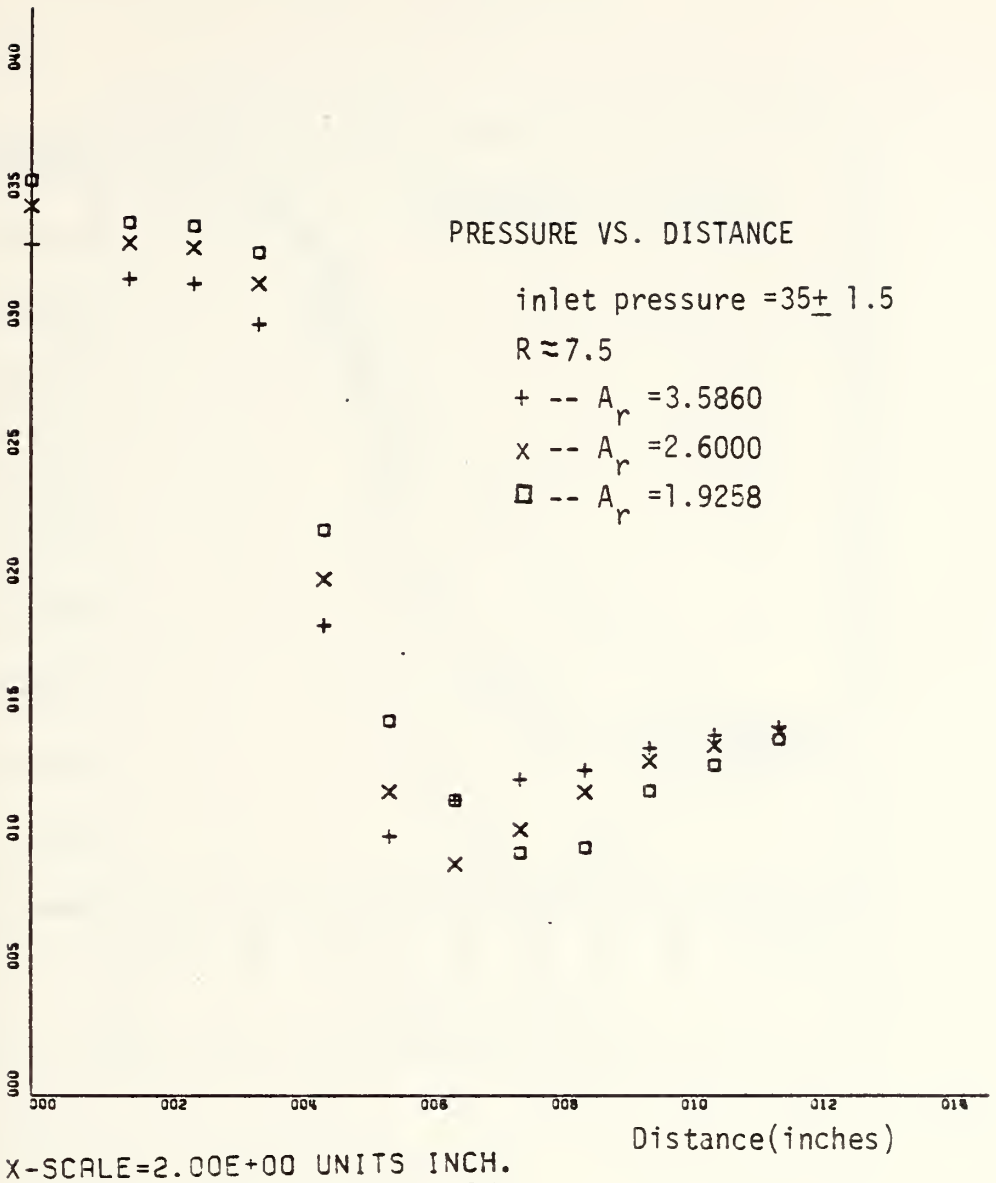


Figure 37. Pressure vs. Distance at
R ≃ 7.5 P = 35psi±1.5

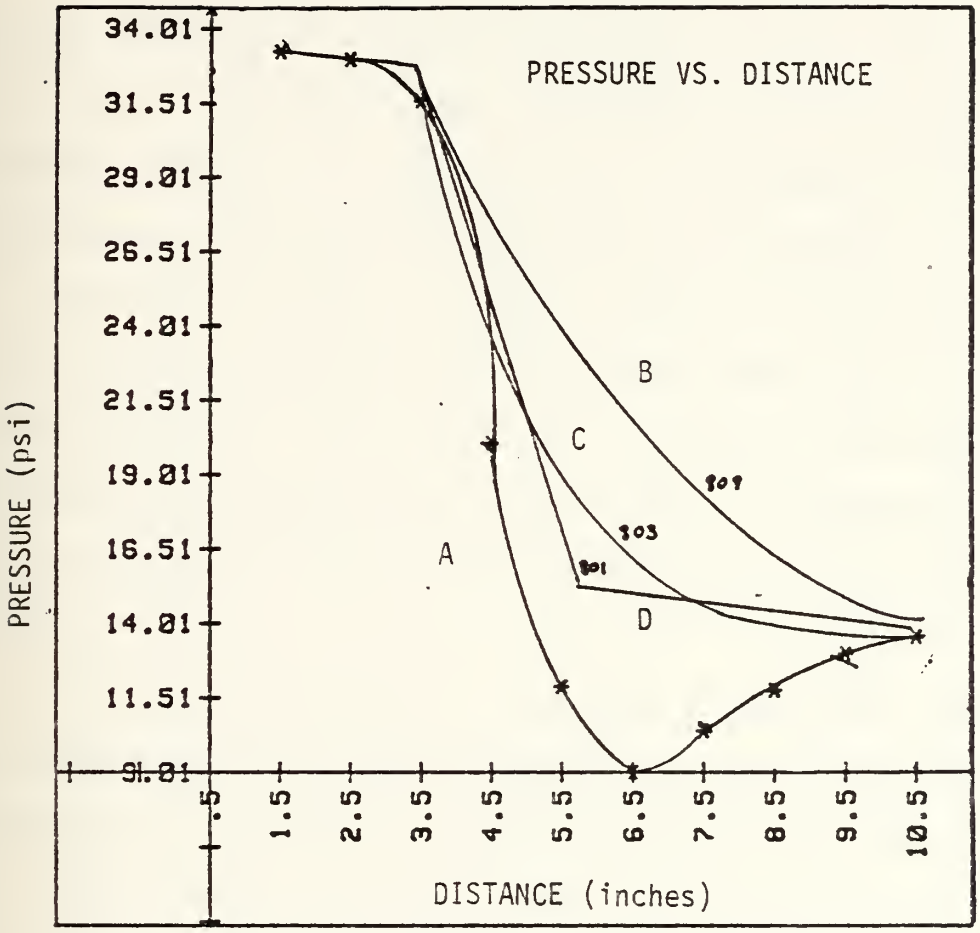


Figure 38. Various Pressure Profiles & Corresponding Exit Velocities

VIII. CONCLUSION

A set of experiments were conducted with an air-water mixture flowing at a mass ratio from 2 to 13. The experiments correlated well with a dual-phase two-component computer program. It appears that the program will permit prediction of the exit velocities to an accuracy of 10% for two-phase nozzles. At small nozzle area ratios, accuracies between theoretical and experimental are better; approximately 5%. All predicted velocities are higher than measured experimental values due to estimation of the drop size and the initial kinetic energy of the liquid at injection point.

It would be desirable to develop a drop size subroutine to better estimate varying drop size. The experimental system can be improved by velocity measurement devices at the inlet. Input of the gas and liquid velocities are necessary in the dual-phase two-component program and thus these measurement devices are vital for better accuracy.

Due to the insensitivity of the pressure distribution, it appears that any reasonable approximation to the pressure profile can be employed in the two-phase two-component flow program. For a given nozzle exit area and inlet pressure, a pressure distribution curve can be obtained through the experimental system. This distribution can therefore be used to obtain good results.

APPENDIX A: SAMPLE P(X) PROGRAM

```
      $JOB
 1          REAL P(75),X(75),PX,FX
 2          INTEGER N,K,NP1,NX
 3          A=35.3654923
 4          B=5.6E5EE777
 5          C=14.39
 6          D=0.C4731
 7          E=.4448C2
 8          NX=75
 9          P1=35.0
10          P2=8.C
11          PREF=8.0
12          XREF=1C.C
13          N=74
14          NP1=N+1
15          PX=(P1-P2)/380
16          CC 10 K=1,N
17             X(K)=7.7*(K-1)/(N-1)
18             DX=7.7-X(K)
19             IF (X(K).LE.0.7)P(K)=P2+PX*E*(855-A*(X(K)+.5)**B)
20             IF (X(K).GT.0.7) P(K)=P2+PX*E*(C*DX+D*DX**4.9)
21             IF(K .EQ.1)GO TO 1C
22             FRAC=(P(K-1)-PREF)/(P(K-1)-P(K))
23             IF (FRAC.GE.0 .AND.FRAC.LE.1)XXREF=X(K-1)+FRAC*(X(K)-X(K-1))
24       10 CONTINUE
25          FX=XREF/XXREF
26          DO 15 K=1,N
27       15    X(K)=FX*X(K)
28          X(NP1)=1E5
29          P(NP1)=1E5
30          CC 20 K=1,75,3
31       20    WRITE(6,100)P(K),X(K),P(K+1),X(K+1),P(K+2),X(K+2)
32          STOP
33      100 FORMAT(6E12.6)
34          END
```

APPENDIX B: SAMPLE HEAT CAPACITY PROGRAM

```
$JOB
      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
     1    D6,D7,D8,D9,M,W
      INTEGER N,J,I,Q,K,X
      DATA PRESS/.01,.4,.7,1.0,4.0,7.0,10.0,40.0,70.0/
      READ (5,100)((TABLE(J,I),I=1,10),J=1,16)
      DO 10 N=1,9
        PRESS(N)=PRESS(N)*14.696
10    CONTINUE
      DO 20 J=1,16
        DO 30 I=2,10
          TABLE(J,I)=TABLE(J,I)*.0685590
30      CONTINUE
20    CONTINUE
      M=0.0
      DO 91 J=1,16
        TEMP(J) =400.0 +M
        M=M+10.0
        W=0.0
        DO 90 I=1,11
          P(I)=W
          N=1
          Q=N+1
          W=100.0+W
15        IF (ABS(TEMP(J)- TABLE(N,1)).GT .001) GO TO 25
            Q=0
            GO TO 50
25        CONTINUE
          IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
     1      GO TO 50
            N=1+N
            Q=N+1
            GO TO 15
50        CONTINUE
          K=2
          X=K+1
          IF(P(I).GT. .0001)GO TO 49
            X=0
            GO TO 60
```

```
49      IF(ABS(P(I) -PRESS(K)).GT..001) GO TO 55
          X=0
          GO TO 60
55      CONTINUE
        IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GO TO 60
          K=1+K
          X=K+1
          GO TO 55
60      CONTINUE
        IF((O.NE. 0) .OR. (X .NE. 0))GO TO 61
          ANS(I)=TABLE (N,K)
          GO TO 90
        CONTINUE
61      IF(O .NE. 0)  GO TO 63
          D1 = TABLE(N,K)-TABLE(N,X)
          D7 = PRESS(K-1) -PRESS(X-1)
          D8 =PRESS(K-1)-P(I)
          D9 =(D8/D7)*D1
          ANS(I)=D9+TABLE(N,K)
          GO TO 90
63      CONTINUE
        IF (X.NE. 0) GO TO 70
          D1 = (TABLE(N,K)-TABLE(O,K))
          D3 = TABLE(N,1)-TABLE(O,1)
          D4 =TABLE(N,1) -TEMP(J)
          D9 =(D4/D3)*D1
          ANS(I) =D9+(TABLE(N,K))
          GO TO 90
70      CONTINUE
        D1 =TABLE(N,K)-TABLE(O,K)
        D2=TABLE(N,X)-TABLE(O,X)
        D3=TABLE(N,1)-TABLE(O,1)
        D4=TABLE(N,1)-TEMP(J)
```

```
            C5=(C4/D3)*C1
            C6=(C4/D3)*D2
            D10=C5+TABLE(N,K)
            D11=C6+TABLE(N,K)
            D7=(PRESS(K-1)-PRESS(X))
            D8=PRESS(K-1)-P(I)
            C9=(C8/D7)*(D10-D11)
            ANS(I)=D9+C1C
 90     CONTINUE
        WRITE(6,150)TEMP(J)
        WRITE(6,200)P(1),ANS(1),P(2),ANS(2),P(3),ANS(3)
        WRITE(6,200)P(4),ANS(4),P(5),ANS(5),P(6),ANS(6)
        WRITE(6,200)P(7),ANS(7),P(8),ANS(8),P(9),ANS(9)
        WRITE(6,250)P(10),ANS(10),P(11),ANS(11)
 91     CONTINUE
        STOP
 100    FORMAT(10F7.4)
 150    FORMAT(F12.6)
 200    FORMAT (6F12.6)
 250    FORMAT (4F12.6)
        END
$ENTRY
360.0   3.4923  3.4935  3.3020  3.5062  3.5495  3.5950  3.6427  4.256   5.132
396.0   3.4928  3.4971  3.5005  3.5038  3.5379  3.5731  3.6095  4.036   4.559
414.0   3.4933  3.4972  3.5002  3.5032  3.5337  3.5651  3.5972  3.963   4.392
432.0   3.4938  3.4973  3.5000  3.5028  3.5302  3.5584  3.5871  3.906   4.265
450.0   3.4946  3.4978  3.5003  3.5027  3.5277  3.5531  3.5789  3.869   4.166
468.0   3.4954  3.4983  3.5005  3.5028  3.5255  3.5485  3.5719  3.822   4.090
486.0   3.4964  3.4990  3.5011  3.5031  3.5240  3.5450  3.5663  3.799   4.025
504.0   3.4976  3.5000  3.5019  3.5038  3.5228  3.5422  3.5614  3.763   3.970
522.0   3.4990  3.5012  3.5030  3.5047  3.5222  3.5398  3.5576  3.741   3.926
540.0   3.5006  3.5026  3.5043  3.5059  3.5229  3.5383  3.5546  3.722   3.889
558.0   3.5025  3.5044  3.5059  3.5074  3.5223  3.5374  3.5525  3.705   3.857
576.0   3.5045  3.5063  3.5076  3.5091  3.5229  3.5369  3.5508  3.692   3.831
594.0   3.5069  3.5085  3.5098  3.5112  3.5240  3.5371  3.5500  3.689   3.808
612.0   3.5094  3.5109  3.5121  3.5134  3.5254  3.5375  3.5497  3.671   3.788
630.0   3.5122  3.5137  3.5148  3.5160  3.5273  3.5386  3.5498  3.662   3.771
720.0   3.5305  3.5316  3.5325  3.5333  3.5416  3.5500  3.5583  3.641   3.717
```

```
$JOB
      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
     1   D6,D7,D8,D9,M,W,MWS(20)
      INTEGER N,J,I,C,K,X
      DATA PRESS/.01,.4,.7,1.0,4.0,7.0,10.0,40.0,70.0/
      READ (5,100)((TABLE(J,I),I=1,10),J=1,16)
      DO 10 N=1,9
        PRESS(N)=PRESS(N)*14.696
10    CONTINUE
      DO 20 J=1,16
        DO 30 I=2,10
          TABLE(J,I)=TABLE(J,I)*.0807223
30      CONTINUE
20    CONTINUE
      M=0.0
      DO 92 J=1,16
        TEMP(J)=400.0 +M
        M=M+10.0
        W=0.0
        DO 91 I=1,11
          P(I)=W
          N=1
          C=N+1
          W=100.0+W
15        IF (ABS(TEMP(J)- TABLE(N,1)).GT .001) GO TO 25
            Q=C
            GO TO 50
25        CONTINUE
          IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
     1      GO TO 50
            N=1+N
            Q=N+1
            GO TO 15
50        CONTINUE
          K=2
          X=K+1
          IF(P(I).GT. .0001)GO TO 49
            X=C
            GO TO 60
49        IF(ABS(P(I) -PRESS(K)).GT..001) GO TO 55
            X=C
            GO TO 60
```

```
55      CONTINUE
        IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GO TO 60
          K=1+K
          X=K+1
          GO TO 55
60      CONTINUE
        IF((C.NE. 0) .OR. (X .NE. 0))GO TO 61
          ANS(I)=TABLE (N,K)
          GO TO 90
        CONTINUE
61      IF(C .NE. C)  GO TO 63
          D1 = (TABLE(N,K)-TABLE(N,X))
          D7 = (PRESS(K-1) -PRESS(X-1))
          D8 =PRESS(K-1)-P(I)
          D9 =ABS((D8/D7)*D1)
          ANS(I)=D9+TABLE(N,K)
          GO TO 90
63      CONTINUE
        IF (C.NE. C) GO TO 70
          D1 = (TABLE(N,K)-TABLE(Q,K))
          D3 = TABLE(N,1)-TABLE(Q,1)
          D4 =TABLE(N,1) -TEMP(J)
          D9 =ABS((D4/D3)*D1)
          ANS(I) =(TABLE(N,K))-D9
          GO TO 90
70      CONTINUE
        D1 =TABLE(N,K)-TABLE(Q,K)
        D2=TABLE(N,X)-TABLE(Q,X)
        D3=TABLE(N,1)-TABLE(Q,1)
        D4=TABLE(N,1)-TEMP(J)
```

```
            D5=ABS((D4/D2)*D1)
            D6=ABS((D4/D2)*D2)
            D10=TABLE(N,K)-D5
            D11=TABLE(N,X)-D6
            D7=(PRESS(K-1)-PRESS(X))
            D8=PRESS(K-1)-P(I)
            D9=ABS((D8/D7)*(D10-D11))
            ANS(I)=D9+D10
 90       IF (P(I).LT..001)P(I)=.00001
          MWS(I)=(.3685*TEMP(J)*ANS(I)/P(I))
 91       CONTINUE
          WRITE(6,150)TEMP(J)
          WRITE(6,200)P(1),MWS(1),P(2),MWS(2),P(3),MWS(3)
          WRITE(6,200)P(4),MWS(4),P(5),MWS(5),P(6),MWS(6)
          WRITE(6,200)P(7),MWS(7),P(8),MWS(8),P(9),MWS(9)
          WRITE(6,250)P(10),MWS(10),P(11),MWS(11)
 92       CONTINUE
          STOP
 100      FORMAT(9F7.4,F7.3)
 150      FORMAT(F12.6)
 200      FORMAT (6F12.6)
 250      FORMAT (4F12.6)
          END
$ENTRY
360.0   .01365  .54648  .95700  1.3681  5.5110  9.7120  13.976  60.13   112.7
396.0   .01241  .49666  .86860  1.2429  4.9960  8.7860  12.613  52.88   96.30
414.0   .01187  .47502  .83160  1.1885  4.7730  8.3880  12.031  49.99   90.19
432.0   .01138  .45519  .79680  1.1390  4.5730  8.0260  11.503  47.48   84.99
450.0   .01092  .43695  .76490  1.0930  4.3840  7.6940  11.021  45.18   80.48
468.0   .01050  .42011  .73540  1.0509  4.2121  7.3850  10.579  43.15   76.51
486.0   .01011  .40453  .70810  1.0117  4.0540  7.1080  10.172  41.31   72.98
504.0   .00975  .39006  .68270  0.9755  3.9070  6.8480   9.797  39.64   69.81
522.0   .00941  .37660  .65910  0.9417  3.7710  6.6170   9.449  38.12   66.95
540.0   .00910  .36403  .63710  0.9102  3.6440  6.3830   9.125  36.72   64.34
558.0   .00881  .35227  .61650  0.8808  3.5250  6.1730   8.824  35.42   61.96
576.0   .00853  .34126  .59720  0.8532  3.4140  5.9770   8.542  34.22   59.77
594.0   .00827  .33098  .57910  0.8273  3.3110  5.7940   8.278  33.11   57.74
612.0   .00802  .32117  .56210  0.8029  3.2129  5.6210   8.030  32.07   55.86
630.0   .00780  .31198  .54600  0.7800  3.1196  5.4590   7.797  31.10   54.11
720.0   .00683  .27297  .47777  0.6823  2.7277  4.7710   6.811  27.04   46.89
```

APPENDIX D: SAMPLE PROPERTY TABLE

```
$ENTRY
400.0
0.0          .2484          100.0          .2514          200.0          .2571          CAG 0010
300.0        .2626          400.0          .2578          500.0          .2730          CAG 0020
600.0        .2779          700.0          .2842          800.0          .2962          CAG 0030
900.0        .3003          1000.0         .3043                 1.E5                 1.E5CAG 0040
410.0                                                                                   CAG 0050
0.0          .2484          100.0          .2532          200.0          .2569          CAG 0060
300.0        .2621          400.0          .2672          500.0          .2721          CAG 0070
600.0        .2769          700.0          .2823          800.0          .2918          CAG 0080
900.0        .2976          1000.0         .3030                 1.E5                 1.E5CAG 0090
420.0                                                                                   CAG 0100
0.0          .2484          100.0          .2531          200.0          .2576          CAG 0110
300.0        .2616          400.0          .2665          500.0          .2712          CAG 0120
600.0        .2758          700.0          .2815          800.0          .2894          CAG 0130
900.0        .2950          1000.0         .3000                 1.E5                 1.E5CAG 0140
430.0                                                                                   CAG 0150
0.0          .2484          100.0          .2529          200.0          .2564          CAG 0160
300.0        .2612          400.0          .2658          500.0          .2704          CAG 0170
600.0        .2748          700.           .2801          800.0          .2869          CAG 0180
900.0        .2924          1000.0         .2970                 1.E5                 1.E5CAG 0190
440.0                                                                                   CAG 0200
0.0          .2484          100.0          .2527          200.0          .2561          CAG 0210
300.         .2607          400.0          .2651          500.0          .2695          CAG 0220
600.0        .2737          700.0          .2787          800.0          .2847          CAG 0230
900.0        .2898          1000.0         .2942                 1.E5                 1.E5CAG 0240
450.0                                                                                   CAG 0250
0.0          .2484          100.0          .2526          200.0          .2559          CAG 0260
300.0        .2602          400.0          .2645          500.0          .2686          CAG 0270
600.0        .2726          700.0          .2774          800.0          .2825          CAG 0280
900.0        .2872          1000.0         .2915                 1.E5                 1.E5CAG 0290
460.0                                                                                   CAG 0300
0.0          .2484          100.0          .2524          200.0          .2556          CAG 0310
300.0        .2597          400.0          .2638          500.0          .2678          CAG 0320
600.0        .2716          700.0          .2759          800.0          .2804          CAG 0330
```

```
900.0         .2848          1000.0         .2838                  1.E5           1.E5CAG  0350
470.0                                                                                CAG  0360
0.0           .2484          100.0          .2522          200.0         .2554       CAG  0370
300.0         .2594          400.0          .2631          500.0         .2668       CAG  0380
600.0         .2706          700.0          .2746          800.0         .2786       CAG  0390
900.0         .2826          1000.0         .2863                  1.E5           1.E5CAG  0400
+.480000E+03                                                                         CAG  0410
+.000000E+00+.248400E-00+.100000E+03+.252000E-00+.200000E+03+.255200E-00CAG  0420
+.300000E+03+.258300E-00+.400000E+03+.261200E-00+.500000E+03+.263900E-00CAG  0430
+.600000E+03+.266500E-00+.700000E+03+.271200E-00+.800000E+03+.276000E-00CAG  0440
+.900000E+03+.280500E-00+.100000E+04+.284100E-00+.100000E+06+.100000E+06CAG  0450
+.490000E+03                                                                         CAG  0460
+.000000E-10+.248400E-00+.100000E+03+.251900E-00+.200000E+03+.254900E-00CAG  0470
+.300000E+03+.258300E-00+.400000E+03+.261700E-00+.500000E+03+.265000E-00CAG  0480
+.600000E+03+.268400E-00+.700000E+03+.271700E-00+.800000E+03+.275200E-00CAG  0490
+.900000E+03+.278500E-00+.100000E+04+.281800E-00+.100000E+06+.100000E+06CAG  0500
+.500000E+03                                                                         CAG  0510
+.000000E+00+.248400E+00+.100000E+03+.251700E+00+.200000E+03+.254700E+00CAG  0520
+.300000E+03+.257800E+00+.400000E+03+.261000E+00+.500000E+03+.264000E+00CAG  0530
+.600000E+03+.267300E+00+.700000E+03+.270500E+00+.800000E+03+.273700E+00CAG  0540
+.900000E+03+.276800E+00+.100000E+04+.280000E+00+.100000E+06+.100000E+06CAG  0550
+.510000E+03                                                                         CAG  0560
+.000000E+00+.248400E+00+.100000E+03+.251600E+00+.200000E+03+.254400E+00CAG  0570
+.300000E+03+.257300E+00+.400000E+03+.260400E+00+.500000E+03+.263300E+00CAG  0580
+.600000E+03+.266400E+00+.700000E+03+.269400E+00+.800000E+03+.272400E+00CAG  0590
+.900000E+03+.275400E+00+.100000E+04+.278300E+00+.100000E+06+.100000E+06CAG  0600
+.520000E+03                                                                         CAG  0610
+.000000E+00+.248400E+00+.100000E+03+.251400E+00+.200000E+03+.254200E+00CAG  0620
+.300000E+03+.256900E+00+.400000E+03+.259800E+00+.500000E+03+.262600E+00CAG  0630
+.600000E+03+.265400E+00+.700000E+03+.268300E+00+.800000E+03+.271200E+00CAG  0640
+.900000E+03+.274000E+00+.100000E+04+.276800E+00+.100000E+06+.100000E+06CAG  0650
+.530000E+03                                                                         CAG  0660
+.000000E+00+.248400E+00+.100000E+03+.251200E+00+.200000E+03+.253900E+00CAG  0670
+.300000E+03+.256500E+00+.400000E+03+.259100E+00+.500000E+03+.261900E+00CAG  0680
+.600000E+03+.264600E+00+.700000E+03+.267200E+00+.800000E+03+.270100E+00CAG  0690
+.900000E+03+.272800E+00+.100000E+04+.275500E+00+.100000E+06+.100000E+06CAG  0700
+.540000E+03                                                                         CAG  0710
+.000000E+00+.248400E+00+.100000E+03+.251100E+00+.200000E+03+.253600E+00CAG  0720
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+.600000E+03+.263900E+00+.700000E+03+.266500E+00+.800000E+03+.269100E+00CAG  0740
+.900000E+03+.271700E+00+.100000E+04+.274200E+00+.100000E+06+.100000E+06CAG  0750
+.550000E+03                                                                         CAG  0760
+.000000E+00+.248400E+00+.100000E+03+.250900E+00+.200000E+03+.253400E+00CAG  0770
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+.600000E+03+.263200E+00+.700000E+03+.265700E+00+.800000E+03+.268100E+00CAG  0790
+.900000E+03+.270600E+00+.100000E+04+.273100E+00+.100000E+06+.100000E+06CAG  0800
+.560000E+03                                                                         CAG  0810
+.000000E+00+.248400E+00+.100000E+03+.250700E+00+.200000E+03+.253200E+00CAG  0820
+.300000E+03+.255600E+00+.400000E+03+.257900E+00+.500000E+03+.260200E+00CAG  0830
+.600000E+03+.262600E+00+.700000E+03+.265000E+00+.800000E+03+.267200E+00CAG  0840
+.900000E+03+.269600E+00+.100000E+04+.272000E+00+.100000E+06+.100000E+06CAG  0850
+.570000E+03+.100000E+01                                                              CAG  0860
+.000000E+00+.248400E+00+.100000E+03+.250500E+00+.200000E+03+.253000E+00CAG  0870
+.300000E+03+.255400E+00+.400000E+03+.257500E+00+.500000E+03+.259700E+00CAG  0880
+.600000E+03+.261900E+00+.700000E+03+.264100E+00+.800000E+03+.266400E+00CAG  0890
+.900000E+03+.268500E+00+.100000E+04+.271800E+00+.100000E+06+.100000E+06CAG  0900
+.000000E+00                                                                         CBG  0910
+.000000E+00+.460000E+00+.100000E+04+.460000E+00+.100000E+06+.100000E+06CBG  0920
+.100000E+04+.100000E+01                                                             CPG  0930
+.000000E+03+.460000E+00+.100000E+04+.460000E+00+.100000E+06+.100000E+06CBG  0940
400.0                                                                                *AG  0950
0.0           28.010         100.0          28.010         200.0         28.376       *AG  0960
300.0         28.580         400.0          28.955         500.0         29.120       *AG  0970
600.0         29.244         700.0          29.552         800.0         29.590       *AG  0980
900.0         29.770         1000.0         29.940                 1.E5           1.E5*AG  0990
410.0                                                                                *AG  1000
0.0           28.010         100.0          28.198         200.0         28.355       *AG  1010
300.0         28.544         400.0          28.733         500.0         29.032       *AG  1020
600.0         29.150         700.0          29.420         800.0         29.462       *AG  1030
900.0         29.615         1000.0         29.780                 1.E5           1.E5*AG  1040
420.0                                                                                *AG  1050
0.0           28.010         100.0          28.186         200.0         28.332       *AG  1060
```

```
300.0          28.508          400.0          28.730          500.0          28.942          WAG 1070
600.0          29.055          700.0          29.242          800.0          29.331          WAG 1080
900.0          29.460          1000.0         29.600                 1.E5           1.E5*WAG 1090
430.0                                                                                  WAG 1100
0.0            28.010          100.0          28.175          200.0          28.319          WAG 1110
300.0          28.472          400.0          28.658          500.0          28.951          WAG 1120
600.0          28.958          700.0          29.147          800.0          29.200          WAG 1130
900.0          29.312          1000.0         29.425                 1.E5           1.E5*WAG 1140
440.0                                                                                  WAG 1150
0.0            28.010          100.0          28.163          200.0          28.289          WAG 1160
300.0          28.436          400.0          28.625          500.0          28.765          WAG 1170
600.0          28.863          700.0          29.012          800.0          29.070          WAG 1180
900.0          29.165          1000.0         29.255                 1.E5           1.E5*WAG 1190
450.0                                                                                  WAG 1200
0.0            28.010          100.0          28.151          200.0          28.266          WAG 1210
300.0          28.400          400.0          28.583          500.0          28.680          WAG 1220
600.0          28.768          700.0          28.882          800.0          28.940          WAG 1230
900.0          29.020          1000.0         29.090                 1.E5           1.E5*WAG 1240
460.0                                                                                  WAG 1250
0.0            28.010          100.0          28.140          200.0          28.244          WAG 1260
300.0          28.363          400.0          28.482          500.0          28.595          WAG 1270
600.0          28.677          700.0          28.760          800.0          28.817          WAG 1280
900.0          28.880          1000.0         28.940                 1.E5           1.E5*WAG 1290
470.0                                                                                  WAG 1300
0.0            28.010          100.0          28.128          200.0          28.222          WAG 1310
300.0          28.327          400.0          28.422          500.0          28.517          WAG 1320
600.0          28.587          700.0          28.648          800.0          28.700          WAG 1330
900.0          28.750          1000.0         28.790                 1.E5           1.E5*WAG 1340
+.480000E+03                                                                           WAG 1350
+.000000E+00+.280100E+02+.100000E+03+.281160E+02+.200000E+03+.282100E+02*WAG 1360
+.300000E+03+.282950E+02+.400000E+03+.283750E+02+.500000E+03+.284460E+02*WAG 1370
+.600000E+03+.285040E+02+.700000E+03+.285520E+02+.800000E+03+.285900E+02*WAG 1380
+.900000E+03+.286270E+02+.100000E+04+.295180E+02+.100000E+06+.100000E+06*WAG 1390
+.490000E+03                                                                           WAG 1400
+.000000E+00+.280100E+02+.100000E+03+.281104E+02+.200000E+03+.281840E+02*WAG 1410
+.300000E+03+.282520E+02+.400000E+03+.283180E+02+.500000E+03+.283730E+02*WAG 1420
+.600000E+03+.284240E+02+.700000E+03+.284560E+02+.800000E+03+.284880E+02*WAG 1430
+.900000E+03+.285130E+02+.100000E+04+.295380E+02+.100000E+06+.100000E+06*WAG 1440
+.500000E+03                                                                           WAG 1450
+.000000E+00+.280100E+02+.100000E+03+.281921E+02+.200000E+03+.283550E+02*WAG 1460
+.300000E+03+.284160E+02+.400000E+03+.284760E+02+.500000E+03+.285110E+02*WAG 1470
+.600000E+03+.285500E+02+.700000E+03+.285650E+02+.800000E+03+.285960E+02*WAG 1480
+.900000E+03+.286120E+02+.100000E+04+.296480E+02+.100000E+06+.100000E+06*WAG 1490
+.510000E+03                                                                           WAG 1500
+.000000E+00+.280100E+02+.100000E+03+.282080E+02+.200000E+03+.283320E+02*WAG 1510
+.300000E+03+.283840E+02+.400000E+03+.284220E+02+.500000E+03+.284530E+02*WAG 1520
+.600000E+03+.284820E+02+.700000E+03+.284980E+02+.800000E+03+.285110E+02*WAG 1530
+.900000E+03+.285200E+02+.100000E+04+.298100E+02+.100000E+06+.100000E+06*WAG 1540
+.520000E+03                                                                           WAG 1550
+.000000E+00+.280100E+02+.100000E+03+.282068E+02+.200000E+03+.283120E+02*WAG 1560
+.300000E+03+.283915E+02+.400000E+03+.284410E+02+.500000E+03+.284820E+02*WAG 1570
+.600000E+03+.285220E+02+.700000E+03+.285390E+02+.800000E+03+.285450E+02*WAG 1580
+.900000E+03+.285235E+02+.100000E+04+.298350E+02+.100000E+06+.100000E+06*WAG 1590
+.530000E+03                                                                           WAG 1600
+.000000E+00+.280100E+02+.100000E+03+.282058E+02+.200000E+03+.283000E+02*WAG 1610
+.300000E+03+.283120E+02+.400000E+03+.283430E+02+.500000E+03+.283650E+02*WAG 1620
+.600000E+03+.283840E+02+.700000E+03+.283960E+02+.800000E+03+.284030E+02*WAG 1630
+.900000E+03+.283950E+02+.100000E+04+.298480E+02+.100000E+06+.100000E+06*WAG 1640
+.540000E+03                                                                           WAG 1650
+.000000E+00+.280100E+02+.100000E+03+.282048E+02+.200000E+03+.282870E+02*WAG 1660
+.300000E+03+.282920E+02+.400000E+03+.283110E+02+.500000E+03+.283260E+02*WAG 1670
+.600000E+03+.283410E+02+.700000E+03+.283510E+02+.800000E+03+.283560E+02*WAG 1680
+.900000E+03+.283080E+02+.100000E+04+.298640E+02+.100000E+06+.100000E+06*WAG 1690
+.550000E+03                                                                           WAG 1700
+.000000E+00+.280100E+02+.100000E+03+.282040E+02+.200000E+03+.282650E+02*WAG 1710
+.300000E+03+.282680E+02+.400000E+03+.282750E+02+.500000E+03+.282870E+02*WAG 1720
+.600000E+03+.283060E+02+.700000E+03+.283140E+02+.800000E+03+.283180E+02*WAG 1730
+.900000E+03+.280150E+02+.100000E+04+.279920E+02+.100000E+06+.100000E+06*WAG 1740
+.560000E+03                                                                           WAG 1750
+.000000E+00+.280100E+02+.100000E+03+.282032E+02+.200000E+03+.280440E+02*WAG 1760
+.300000E+03+.280480E+02+.400000E+03+.280430E+02+.500000E+03+.280360E+02*WAG 1770
+.600000E+03+.280260E+02+.700000E+03+.280040E+02+.800000E+03+.279840E+02*WAG 1780
```

```
+.900000E+03+.279560E+02+.100000E+04+.279320E+02+.100000E+06+.100000E+06WAG  1790
+.570000E+03+.100000E+01                                                WAG  1800
+.000000E+00+.280100E+02+.100000E+03+.280130E+02+.200000E+03+.280400E+02WAG  1810
+.300000E+03+.280320E+02+.400000E+03+.280130E+02+.500000E+03+.280000E+02WAG  1820
+.600000E+03+.279900E+02+.700000E+03+.279560E+02+.800000E+03+.279450E+02WAG  1830
+.900000E+03+.279100E+02+.100000E+04+.278860E+02+.100000E+06+.100000E+06WAG  1840
+.000000E+00                                                            WBG  1850
+.000000E+00+.180160E+02+.100000E+04+.180160E+02+.100000E+06+.100000E+06WBG  1860
+.100000E+04+.100000E+01                                                WBG  1870
+.000000E+00+.180160E+02+.100000E+04+.180160E+02+.100000E+06+.100000E+06WBG  1880
+.000000E+00+.248400E+00+.100000E+04+.248400E+00+.100000E+06+.100000E+06CAL  1890
+.492000E+03+.100740E+01+.495000E+03+.100600E+01+.500000E+03+.100400E+01CBL  1900
+.505000E+03+.100250E+01+.510000E+03+.100130E+01+.515000E+03+.100040E+01CBL  1910
+.520000E+03+.999500E+00+.525000E+03+.999100E+00+.530000E+03+.998700E+00CBL  1920
+.535000E+03+.998400E+00+.540000E+03+.998200E+00+.545000E+03+.998000E+00CBL  1930
+.550000E+03+.998000E+00+.555000E+03+.997800E+00+.560000E+03+.998000E+00CBL  1940
+.565000E+03+.998000E+00+.570000E+03+.998100E+00+.100000E+06+.100000E+06CBL  1950
+.000000E-00+.000000E-00+.100000E+04+.000000E-00+.100000E+06+.100000E+06LA   1960
+.492000E+03+.107250E+04+.492500E+03+.107000E+04+.493000E+03+.106800E+04LB  1970
+.494000E+03+.106760E+04+.496000E+03+.106550E+04+.500000E+03+.106280E+04LB  1980
+.570000E+03+.102440E+04+.100000E+06+.100000E+06                        LB   1990
400.0         .015          410.0         .017          420.0         .019    PBD  2000
430.0         .021          440.0         .026          450.0         .035    PBD  2010
460.0         .045          470.0         .055          480.0         .065    PBD  2020
+.492000E+03+.900000E-01+.500000E+03+.114000E-00+.505000E+03+.114000E-00PBD  2030
+.510000E+03+.176000E-00+.515000E+03+.232000E-00+.520000E+03+.254000E-00PBD  2040
+.525000E+03+.304000E-00+.530000E+03+.361000E-00+.535000E+03+.424000E-00PBD  2050
+.540000E+03+.502000E-00+.545000E+03+.590000E-00+.550000E+03+.720000E-00PBD  2060
+.555000E+01+.812000E-00+.560000E+01+.930000E-00+.555000E+03+.110000E+01PBD  2070
+.570000E+03+.127200E+01+.100000E+06+.100000E+06                        PBD  2080
400.0         62.418        410.0         62.418        420.0         62.418  BOAL 2090
430.0         62.418        440.0         62.418        450.0         62.418  BOAL 2100
460.0         62.418        470.0         62.418        480.0         62.418  BOAL 2110
+.492000E+03+.624180E+02+.494000E+03+.624220E+02+.496000E+03+.624250E+02BOAL 2120
+.498000E+03+.624260E+02+.500000E+03+.624260E+02+.502000E+03+.624250E+02BOAL 2130
+.504000E+03+.624230E+02+.506000E+03+.624200E+02+.508000E+03+.624150E+02BOAL 2140
+.510000E+03+.624100E+02+.512000E+03+.624030E+02+.514000E+03+.623950E+02BOAL 2150
+.516000E+03+.623870E+02+.518000E+03+.623770E+02+.520000E+03+.623700E+02BOAL 2160
+.522000E+03+.623560E+02+.524000E+03+.623430E+02+.526000E+03+.623300E+02BOAL 2170
+.528000E+03+.623150E+02+.530000E+03+.623020E+02+.532000E+03+.622880E+02BOAL 2180
+.534000E+03+.622730E+02+.536000E+03+.622580E+02+.538000E+03+.622450E+02BOAL 2190
+.540000E+03+.622170E+02+.542000E+03+.621980E+02+.544000E+03+.621780E+02BOAL 2200
+.546000E+03+.621570E+02+.548000E+03+.621360E+02+.550000E+03+.621140E+02BOAL 2210
+.552000E+03+.620910E+02+.554000E+03+.620680E+02+.556000E+03+.620440E+02BOAL 2220
+.558000E+03+.620200E+02+.560000E+03+.619950E+02+.562000E+03+.619700E+02BOAL 2230
+.564000E+03+.619430E+02+.566000E+03+.619180E+02+.568000E+03+.618880E+02BOAL 2240
+.570000E+03+.618610E+02+.100000E+06+.100000E+06                        BOAL 2250
+.492000E+03+.624180E+02+.494000E+03+.624220E+02+.496000E+03+.624250E+02BOBL 2260
+.498000E+03+.624260E+02+.500000E+03+.624260E+02+.502000E+03+.624250E+02BOBL 2270
+.504000E+03+.624230E+02+.506000E+03+.624200E+02+.508000E+03+.624150E+02BOBL 2280
+.510000E+03+.624100E+02+.512000E+03+.624030E+02+.514000E+03+.623950E+02BOBL 2290
+.516000E+03+.623870E+02+.518000E+03+.623770E+02+.520000E+03+.623700E+02BOBL 2300
+.522000E+03+.623550E+02+.524000E+03+.623430E+02+.526000E+03+.623300E+02BOBL 2310
+.528000E+03+.623150E+02+.530000E+03+.623020E+02+.532000E+03+.622880E+02BOBL 2320
+.534000E+03+.622730E+02+.536000E+03+.622580E+02+.538000E+03+.622450E+02BOBL 2330
+.540000E+03+.622170E+02+.542000E+03+.621980E+02+.544000E+03+.621780E+02BOBL 2340
+.546000E+03+.621570E+02+.548000E+03+.621360E+02+.550000E+03+.621140E+02BOBL 2350
+.552000E+03+.620910E+02+.554000E+03+.620680E+02+.556000E+03+.620440E+02BOBL 2360
+.558000E+03+.620200E+02+.560000E+03+.619950E+02+.562000E+03+.619700E+02BOBL 2370
+.564000E+03+.619430E+02+.566000E+03+.619180E+02+.568000E+03+.618880E+02BOBL 2380
+.570000E+03+.618610E+02+.100000E+06+.100000E+06                        BOBL 2390
400.0         .01177        410.0         .01232        420.0         .01325  KAG  2400
430.0         .01250        440.0         .01275        450.0         .01297  KAG  2410
460.0         .01320        470.0         .01344        480.0         .01584  KAG  2420
570.0         .01584        1.            +51.          +5                    KAG  2430
400.0         .00695        410.0         .00772        420.0         .00745  KBG  2440
430.0         .00770        440.0         .00733        450.0         .00819  KBG  2450
460.0         .00849        470.0         .00854        480.0         .00889  KBG  2460
+.492000E+03+.920000E-02+.500000E+03+.934000E-02+.510000E+03+.958000E-02KBG  2470
+.520000E+03+.980000E-02+.530000E+03+.101500E-01+.540000E+03+.103000E-01KBG  2480
+.550000E+03+.105500E-01+.560000E+03+.107900E-01+.570000E+03+.110400E-01KBG  2490
+.100000E+06+.100000E+06                                                KBG  2500
```

```
400.0         4.33          410.0         4.33          420.0         4.33          VIAL2510
430.0         4.33          440.0         4.33          450.0         4.33          VIAL2520
460.0         4.33          470.0         4.33          480.0         4.33          VIAL2530
+.492000E+03+.433000E+01+.500000E+03+.374000E+01+.510000E+03+.316000E+01VIAL2540
+.520000E+03+.272000E+01+.530000E+03+.237000E+01+.540000E+03+.209000E+01VIAL2550
+.550000E+03+.195000E+01+.560000E+03+.165000E+01+.570000E+03+.150000E+01VIAL2560
+.100000E+06+.100000E+06                                                VIAL2570
+.492000E+03+.433000E+01+.500000E+03+.374000E+01+.510000E+03+.316000E+01VIAL2580
+.520000E+03+.272000E+01+.530000E+03+.237000E+01+.540000E+03+.209000E+01VIAL2590
+.550000E+03+.195000E+01+.560000E+03+.165000E+01+.570000E+03+.150000E+01VIAL2600
+.100000E+06+.100000E+06                                                VIAL2610
400.0         .03445        410.0         .03595        420.0         .03568        VIAG2620
430.0         .03630        440.0         .03643        450.0         .03755        VIAG2630
460.0         .03818        470.0         .03840        480.0         .03943        VIAG2640
490.0         .04005        500.0         .04005        510.0         .04130        VIAG2650
520.0         .04100        530.0         .04255        540.0         .04315        VIAG2660
550.0         .04375        560.0         .04435        570.0         .04495        VIAG2670
1.      + 51.         +5                                                VIAG2680
400.0         .01900        410.0         .01940        420.0         .01980        VIBG2690
430.0         .02022        440.0         .02060        450.0         .02100        VIBG2700
460.0         .02145        470.0         .02190        480.0         .02235        VIBG2710
+.492000E+01+.232000E-01+.500000E+03+.234000E-01+.510000E+03+.237000E-01VIBG2720
+.520000E+03+.241000E-01+.530000E+03+.245000E-01+.540000E+03+.249000E-01VIBG2730
+.550000E+03+.253000E-01+.560000E+03+.257000E-01+.570000E+03+.262000E-01VIBG2740
+.100000E+06+.100000E+06                                                VIBG2750
+.492000E+03+.756000E+02+.530000E+03+.726000E+02+.550000E+03+.708000E+02SIG 2760
+.570000E+03+.690000E+02+.100000E+06+.100000E+06                        SIG 2770
```

APPENDIX E: SAMPLE INPUT DATA

```
APRIL 15, 1980    1                NOZZLE D, 2 MPA                          920     1
     1      0      0     30     30     30     1
-0.3          20.0          0.0           0.0          5.28
        .85E-60.C           -0.3          28.02         18.02        208.0
1C10.0          0.C5        290.0         537.0         537.0         20.0
20.0            0.C05       0.005         C.0004        0.003         0.1
10 IN. NCZZLE
  .29CCC1+03   .C0000C      .289564+C3   .138144+00   .288580+03   .276288+00
  .28661E+03   .414432+C0   .283025+03   .552576+C0   .276898+03   .690720+00
  .266995+03   .828864+C0   .252206+03   .967C08+00   .236879+03   .110515+01
  .222415+03   .12433C+C1   .208777+C3   .138144+01   .195929+03   .151958+01
  .183834+03   .165773+C1   .172458+03   .179587+01   .161766+C3   .193402+01
  .151728+03   .207216+C1   .142310+03   .221030+01   .133482+03   .234845+01
  .125216+03   .248659+C1   .117481+C3   .262474+C1   .110251+C3   .276289+01
  .1C35CC+03   .290102+01   .972006+02   .303917+01   .913291+02   .317731+01
  .858612+02   .331546+C1   .807742+C2   .345360+01   .760453+02   .359174+01
  .716549+02   .372989+01   .675810+02   .386803+01   .639046+02   .400618+01
  .6C3CE9+02   .414432+C1   .570700+02   .428246+01   .540765+02   .442061+01
  .513102+02   .455875+01   .487553+C2   .469690+01   .463968+02   .483504+01
  .4422CE+02   .497319+01   .422129+02   .511133+01   .403611+02   .524947+C1
  .38C527+02   .538762+C1   .370764+02   .552576+01   .356211+02   .566391+01
  .342765+02   .58020E+C1   .330328+02   .594C19+01   .318810+02   .607834+01
  .3CP124+02   .621648+01   .298189+02   .635463+01   .288931+02   .649277+01
  .2E02EC+02   .663C91+C1   .272169+02   .676906+01   .264540+02   .690720+01
  .257435+02   .704535+C1   .250505+02   .713349+01   .244000+02   .732163+01
  .237779+02   .745978+01   .231803+02   .759792+01   .226035+02   .772607+01
  .22044E+02   .787421+C1   .215C03+C2   .801235+01   .209684+02   .815050+01
  .2044CE+02   .828864+C1   .199329+02   .842679+01   .194257+C2   .856493+01
  .189235+02   .87030C7+01  .184252+02   .884122+01   .179296+02   .897936+01
  .1743EC+02   .911751+C1   .169438+02   .925565+01   .164525+C2   .939379+01
  .159617+02   .953194+01   .154712+02   .967008+01   .149807+02   .980823+01
  .1449C4+C2   .994637+01   .140000+02   .100845+02   .100000+06   .100000+06
```

APPENDIX F: SAMPLE 140PC CALIBRATION PROGRAM

```
10    DIM X(15,100),Sum(15),Mean(15),Sum2(15),Sd(15)
30    N=10
40    FOR I=1 TO N
50       OUTPUT 709;"AI1VT1"
60       ENTER 709;X(1,I)
70       OUTPUT 709;"AI2VT1"
80       ENTER 709;X(2,I)
90       OUTPUT 709;"AI3VT1"
100      ENTER 709;X(3,I)
110      OUTPUT 709;"AI4VT1"
120      ENTER 709;X(4,I)
130      OUTPUT 709;"AI5VT1"
140      ENTER 709;X(5,I)
150      OUTPUT 709;"AI6VT1"
160      ENTER 709;X(6,I)
170      OUTPUT 709;"AI7VT1"
180      ENTER 709;X(7,I)
190      OUTPUT 709;"AI8VT1"
200      ENTER 709;X(8,I)
210      OUTPUT 709;"AI9VT1"
220      ENTER 709;X(9,I)
230      OUTPUT 709;"AI16VT1"
240      ENTER 709;X(10,I)
250      OUTPUT 709;"AI11VT1"
260      ENTER 709;X(11,I)
261      OUTPUT 709;"AI12VT1"
262      ENTER 709;X(12,I)
263      OUTPUT 709;"AI13VT1"
264      ENTER 709;X(13,I)
267      OUTPUT 709;"AI17VT1"
268      ENTER 709;X(14,I)
270   NEXT I
```

```
280   PRINT "                    CHANNELS"
290   PRINT "    1       2       3       4       5       6       7       8"
300   !
310   PRINT "_____________________________________________________________________
_____"
320   PRINT
330   FOR I=1 TO N
340      PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I),X(4,I),X(5,I),X(6,I),X(7,I),
X(8,I)
350   NEXT I
360   PRINT
370   PRINT "                     CHANNEL"
380   PRINT "    9       10      11      12      13      17"
390   PRINT "_____________________________________________________________________
_____"
400   FOR I=1 TO N
410      PRINT USING "DD.DDDD";X(9,I),X(10,I),X(11,I),X(12,I),X(13,I),X(14,I)
411   NEXT I
413   PRINT
414   PRINT "                          MEAN  ","          STANDARD DEVIATION"
415   PRINT "_____________________________________________________________________
420   PRINT
440   FOR J=1 TO 14
450      Sum(J)=0
460      FOR I=1 TO N
470         Sum(J)=Sum(J)+X(J,I)
480      NEXT I
490      Mean(J)=Sum(J)/N
510   NEXT J
512   FOR J=1 TO 14
513      FOR I=1 TO N
515        Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
516      NEXT I
518      Sd(J)=SQR(Sum2(J)/(N-1))
519      IF J=14 THEN GOTO 523
521   PRINT "channel    ";J,Mean(J),"    ",Sd(J)
522   GOTO 525
523   PRINT "CHANNAL    ";J+3,Mean(J),"    ",Sd(J)
525   NEXT J
526   END
```

APPENDIX G: SAMPLE OUTPUT TO CALIBRATION PROGRAM

THIS DATA IS FOR A PRESSURE OF 0 PSI

CHANNELS							
1	2	3	4	5	6	7	8
1.6588	1.8301	1.7702	1.6914	1.8429	1.7485	1.7900	1.8098
1.6589	1.8305	1.7705	1.6922	1.8431	1.7484	1.7901	1.8101
1.6598	1.8308	1.7715	1.6931	1.8446	1.7500	1.7918	1.8120
1.6605	1.8318	1.7717	1.6935	1.8444	1.7499	1.7916	1.8117
1.6603	1.8317	1.7722	1.6931	1.8446	1.7497	1.7917	1.8117
1.6598	1.8315	1.7716	1.6928	1.8439	1.7495	1.7909	1.8112
1.6596	1.8310	1.7712	1.6925	1.8437	1.7494	1.7909	1.8110
1.6597	1.8310	1.7714	1.6925	1.8441	1.7494	1.7910	1.8112
1.6593	1.8311	1.7712	1.6923	1.8438	1.7496	1.7907	1.8114
1.6594	1.8313	1.7709	1.6927	1.8438	1.7496	1.7906	1.8109

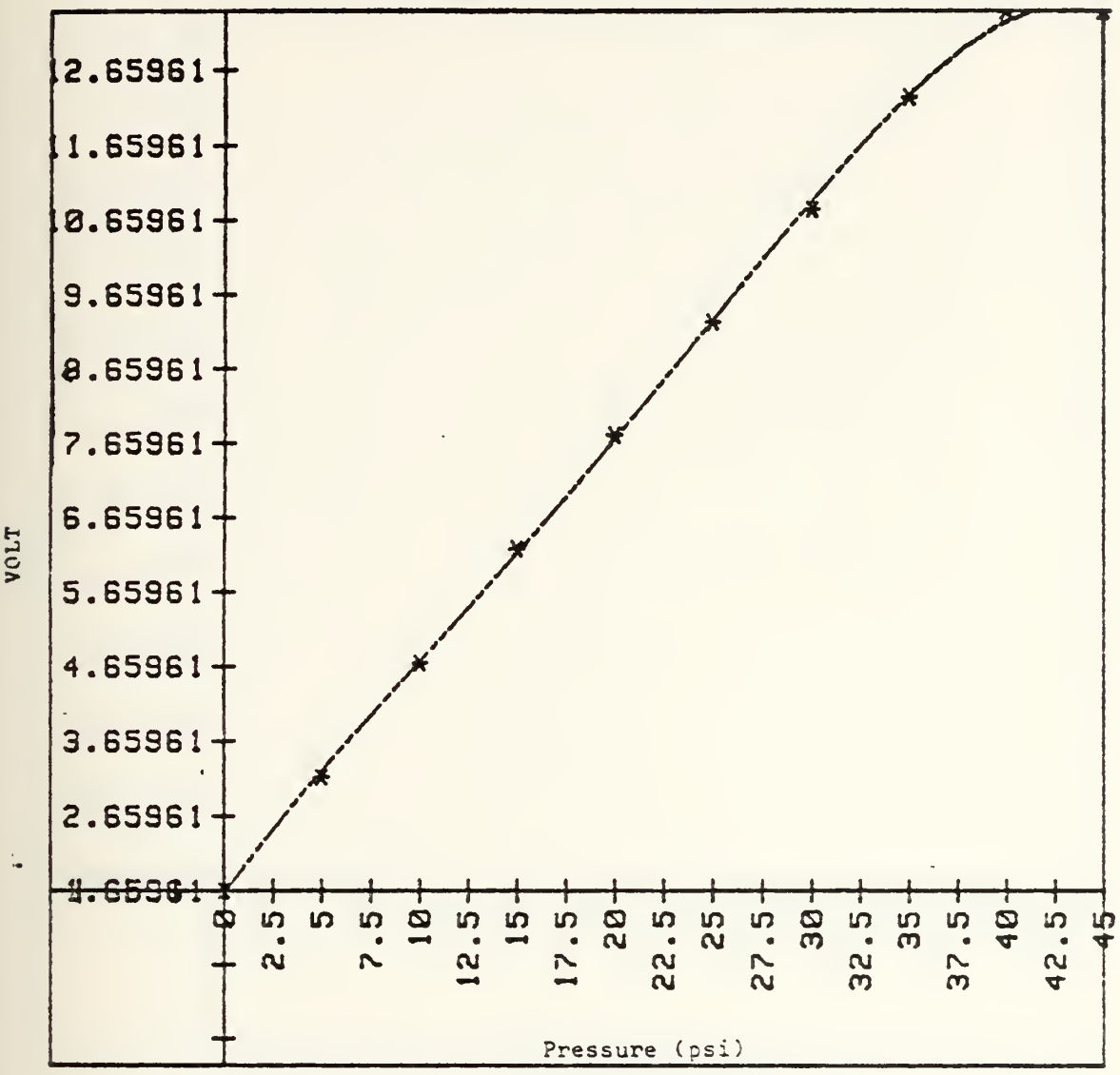
CHANNEL					
9	10	11	12	13	17
1.7941	1.7381	1.7211	1.8335	-.0119	14.8960
1.7946	1.7389	1.7221	1.8336	-.0119	14.9000
1.7961	1.7397	1.7239	1.8353	-.0119	14.9090
1.7958	1.7400	1.7232	1.8341	-.0119	14.9060
1.7960	1.7401	1.7237	1.8351	-.0119	14.9030
1.7957	1.7402	1.7236	1.8347	-.0119	14.9000
1.7955	1.7388	1.7233	1.8340	-.0119	14.8990
1.7959	1.7394	1.7226	1.8342	-.0119	14.9020
1.7958	1.7398	1.7233	1.8338	-.0119	14.9020
1.7954	1.7394	1.7231	1.8341	-.0119	14.9000

		MEAN	STANDARD DEVIATION
channel	1	1.65961	.000542524961023
channel	2	1.83108	.000528730134904
channel	3	1.77124	.000587272414548
channel	4	1.69261	.000583952052826
channel	5	1.84389	.000574359546703
channel	6	1.7494	.000537483849887
channel	7	1.79093	.0006254775953
channel	8	1.8111	.000697614984549
channel	9	1.79549	.000647130417905
channel	10	1.73944	.000668663675633
channel	11	1.72299	.000847807630172
channel	12	1.83424	.000607728009338
channel	13	-.0118729	8.1846740246E-6
channal	17	14.9017	.00368329562575

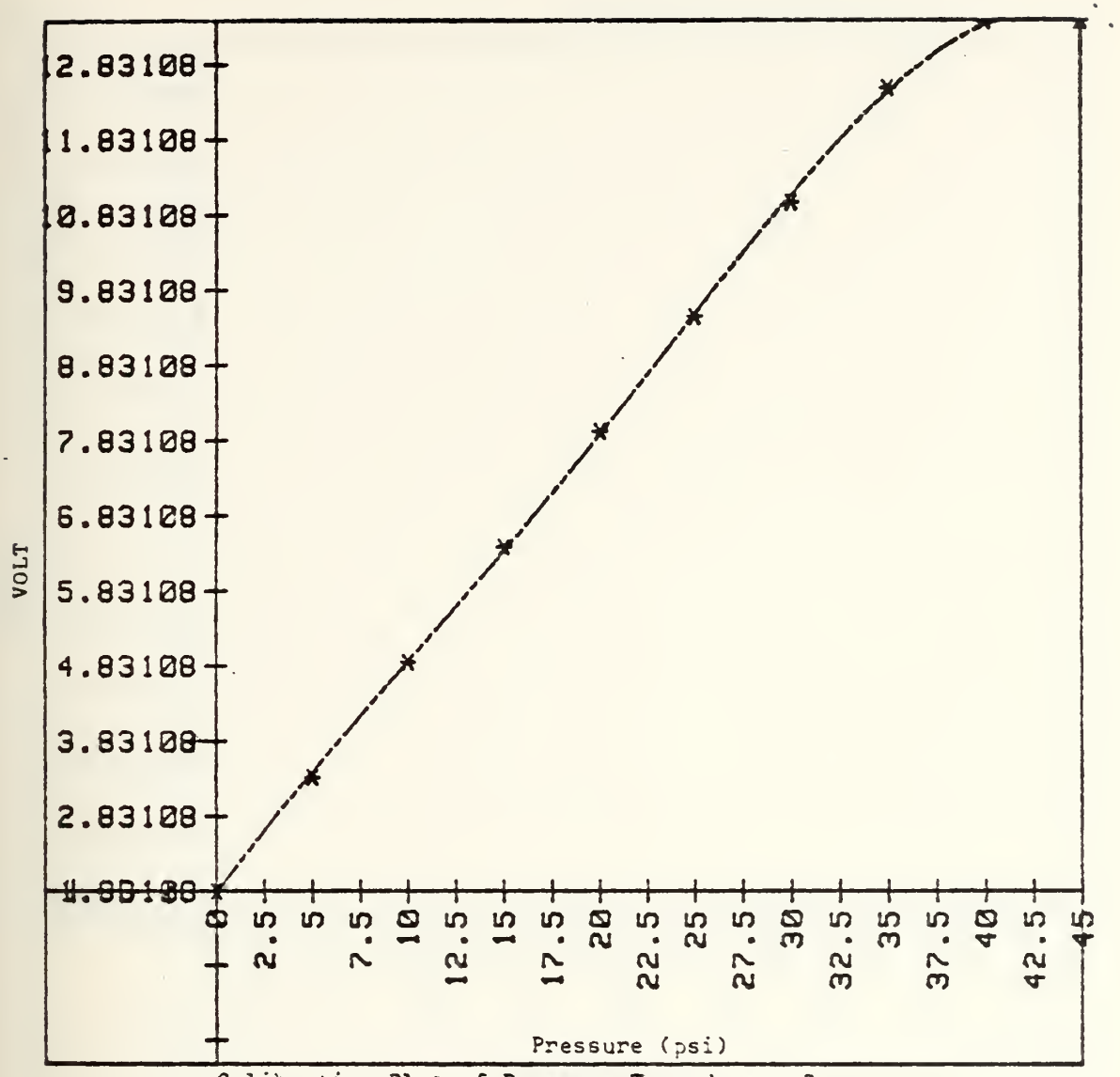
```
PRINT "THIS PROGRAM IS USED TO CALIBRATE 100 PSI PRESSURE TRANSDUCERS."
PRINT "ENTER THE AMOUNT OF READINGS YOU WISH THE PROGRAM TO AVERAGE"
DIM X(11,100),Sum(11),Mean(11),Sum2(11),Sd(11)
PRINT
INPUT N
Y=0
FOR T=1 TO 11
  PRINT
  PRINT
  PRINT "THIS RUN IS FOR A PRESSURE OF";Y;"PSI"
  PRINT "_____"
  PRINT
  PRINT " ONCE THE PRESSURE IS SET AT";Y;"PSI"
  PRINT "PUSH THE CONTINUE BUTTON AND WAIT FOR DATA."
  Y=Y+10
  PAUSE
FOR I=1 TO N
   OUTPUT 709;"AI12VT1"
   ENTER 709;X(1,I)
   OUTPUT 709;"AI14VT1"
   ENTER 709;X(2,I)
   OUTPUT 709;"AI15VT1"
   ENTER 709;X(3,I)
NEXT I
```

```
PRINT "                    CHANNELS"
PRINT "    1,      2       3  "
PRINT "_____________________________________________________"
PRINT
FOR I=1 TO N
   PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I)
NEXT I
PRINT
PRINT "                          MEAN  ","         STANDARD DEVIATION"
PRINT "_____________________________________________________"
PRINT
FOR J=1 TO 3
   Sum(J)=0
   FOR I=1 TO N
      Sum(J)=Sum(J)+X(J,I)
   NEXT I
   Mean(J)=Sum(J)/N
NEXT J
FOR J=1 TO 3
   FOR I=1 TO N
     Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
   NEXT I
   Sd(J)=SQR(Sum2(J)/(N-1))
PRINT "channel   ";J,Mean(J),"    ",Sd(J)
NEXT J
PRINT
PRINT
PRINT
NEXT T
END
```

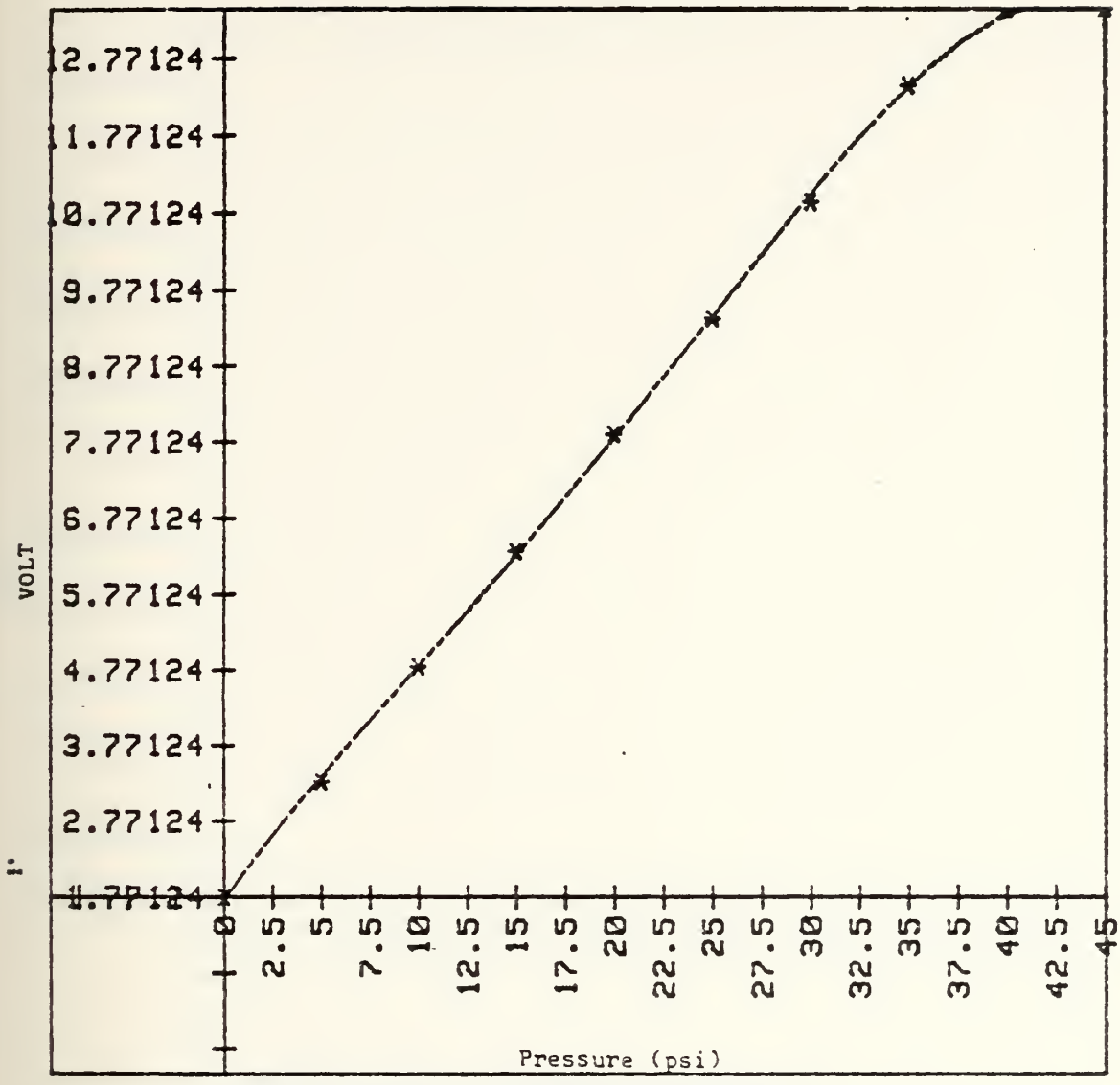
APPENDIX I: CALIBRATION PLOT OF PRESSURE TRANSDUCERS



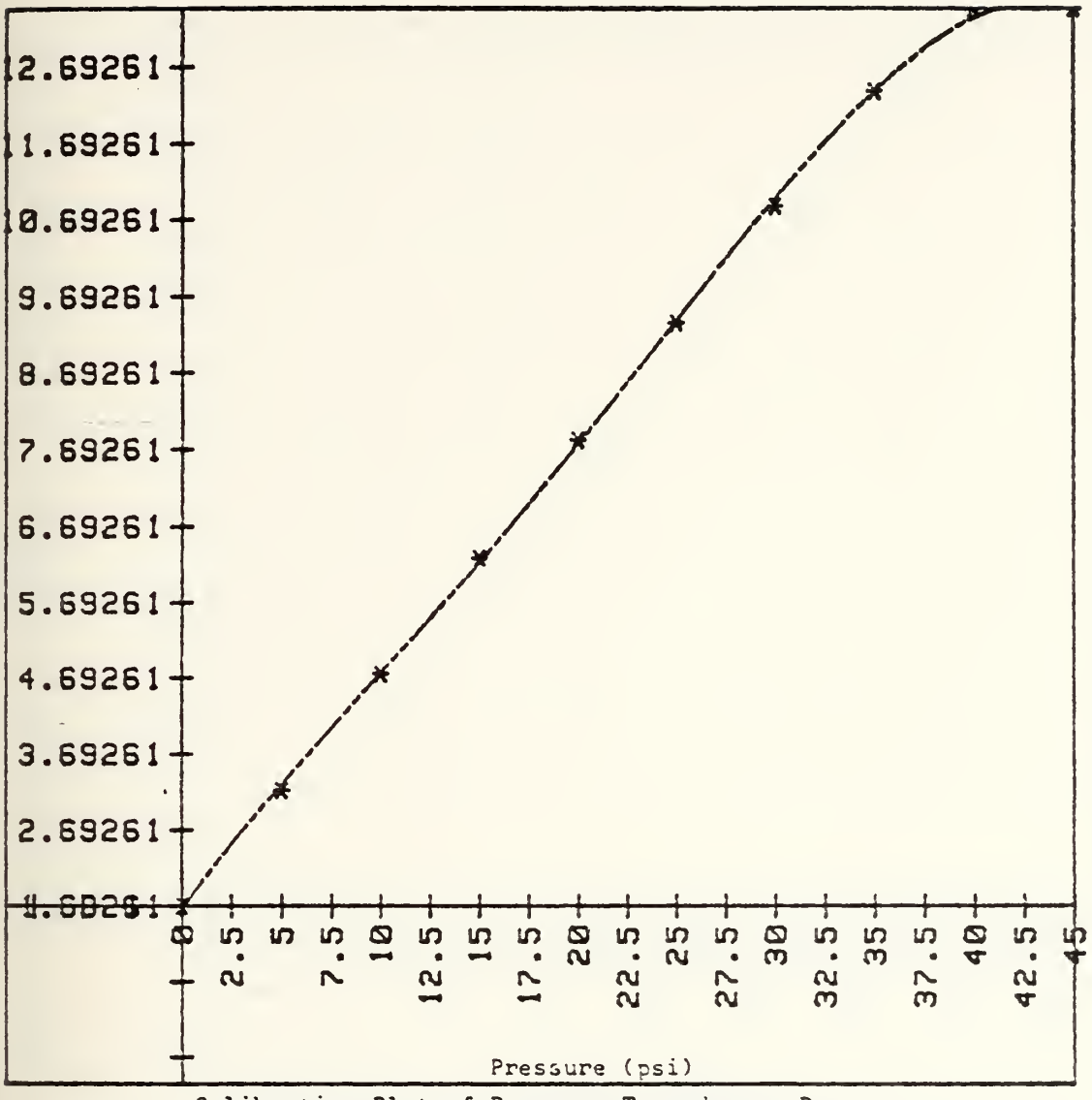
Calibration Plot of Pressure Transducer A



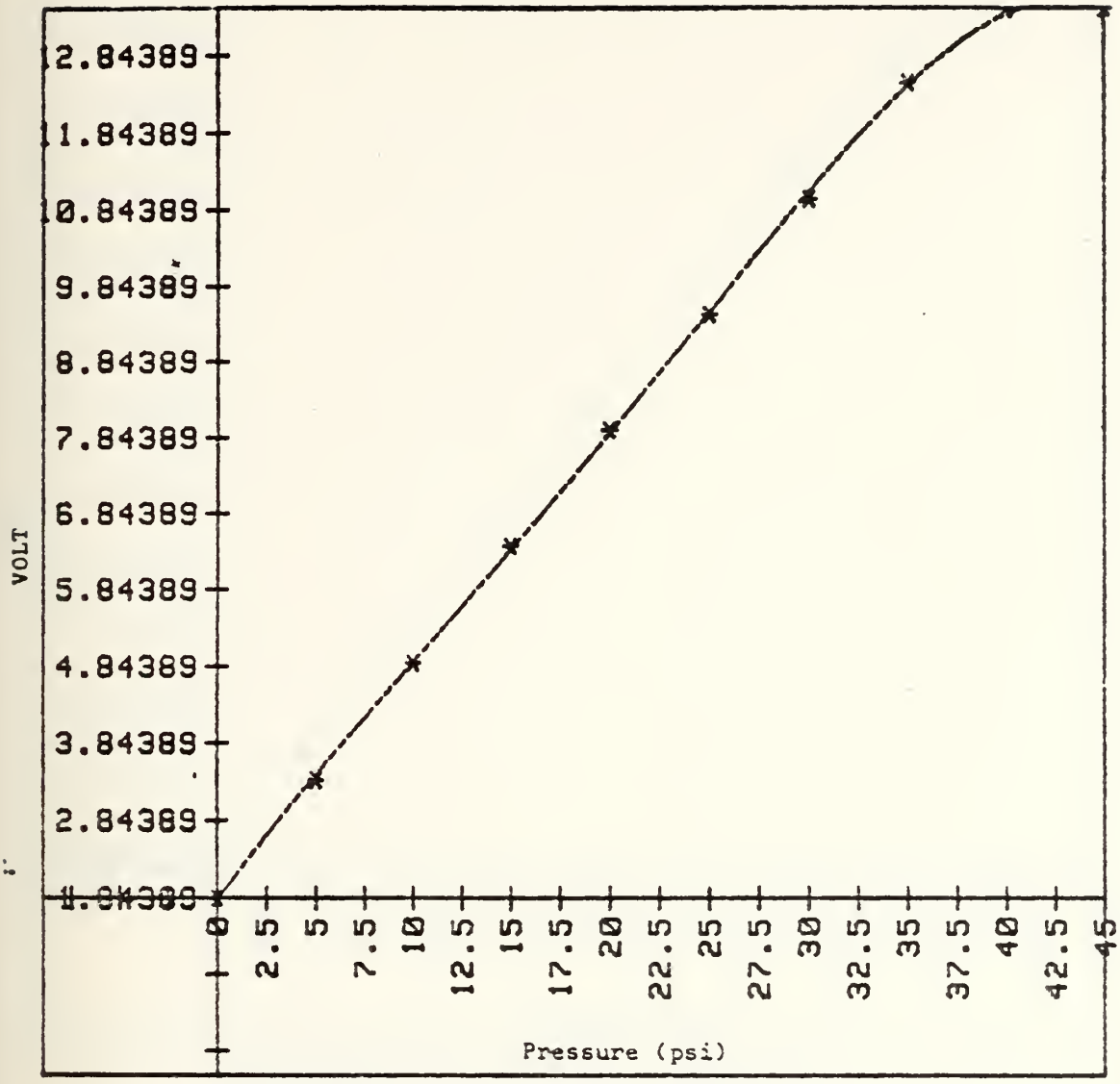
Calibration Plot of Pressure Transducer B



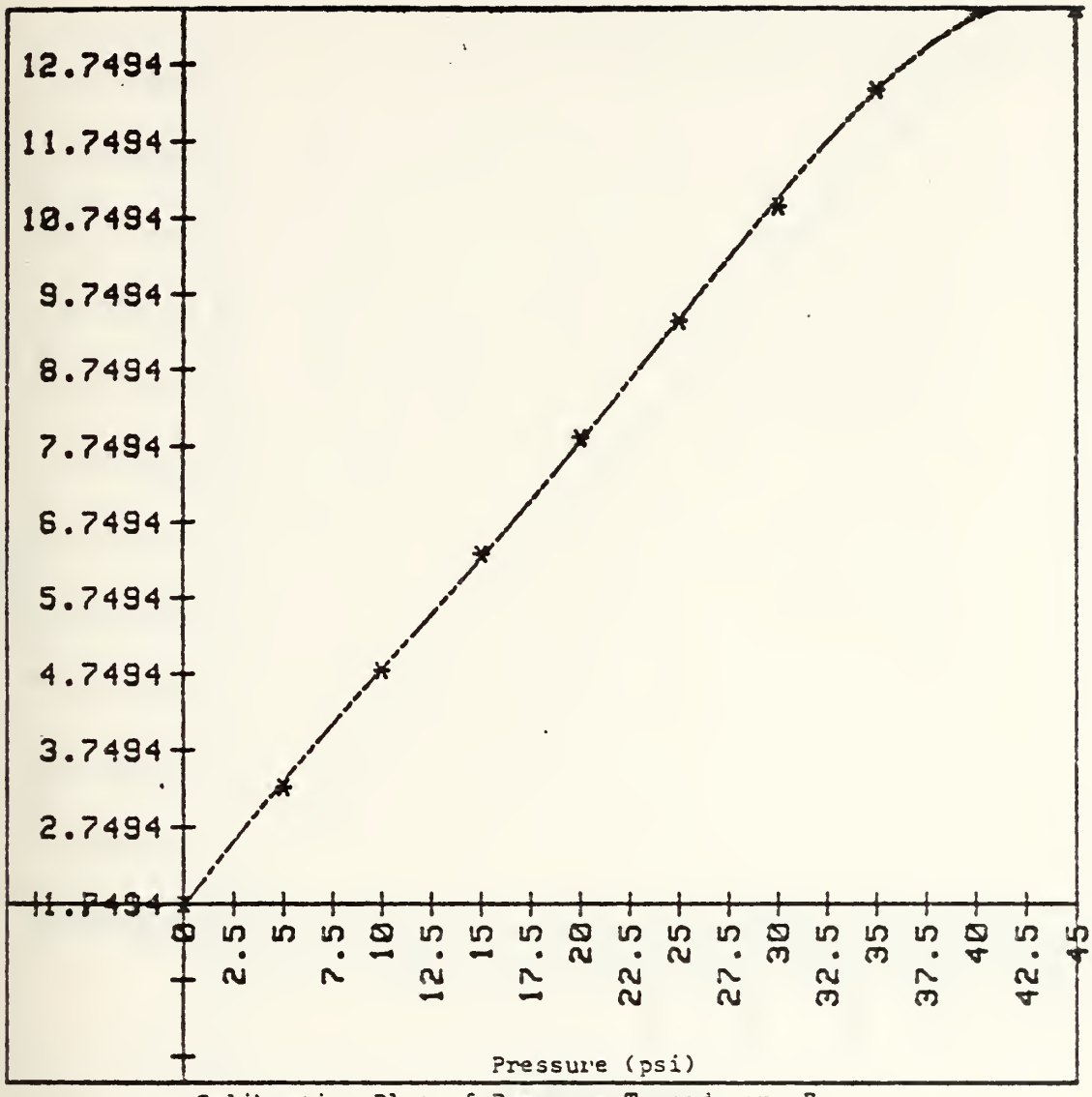
Calibration Plot of Pressure Transducer C



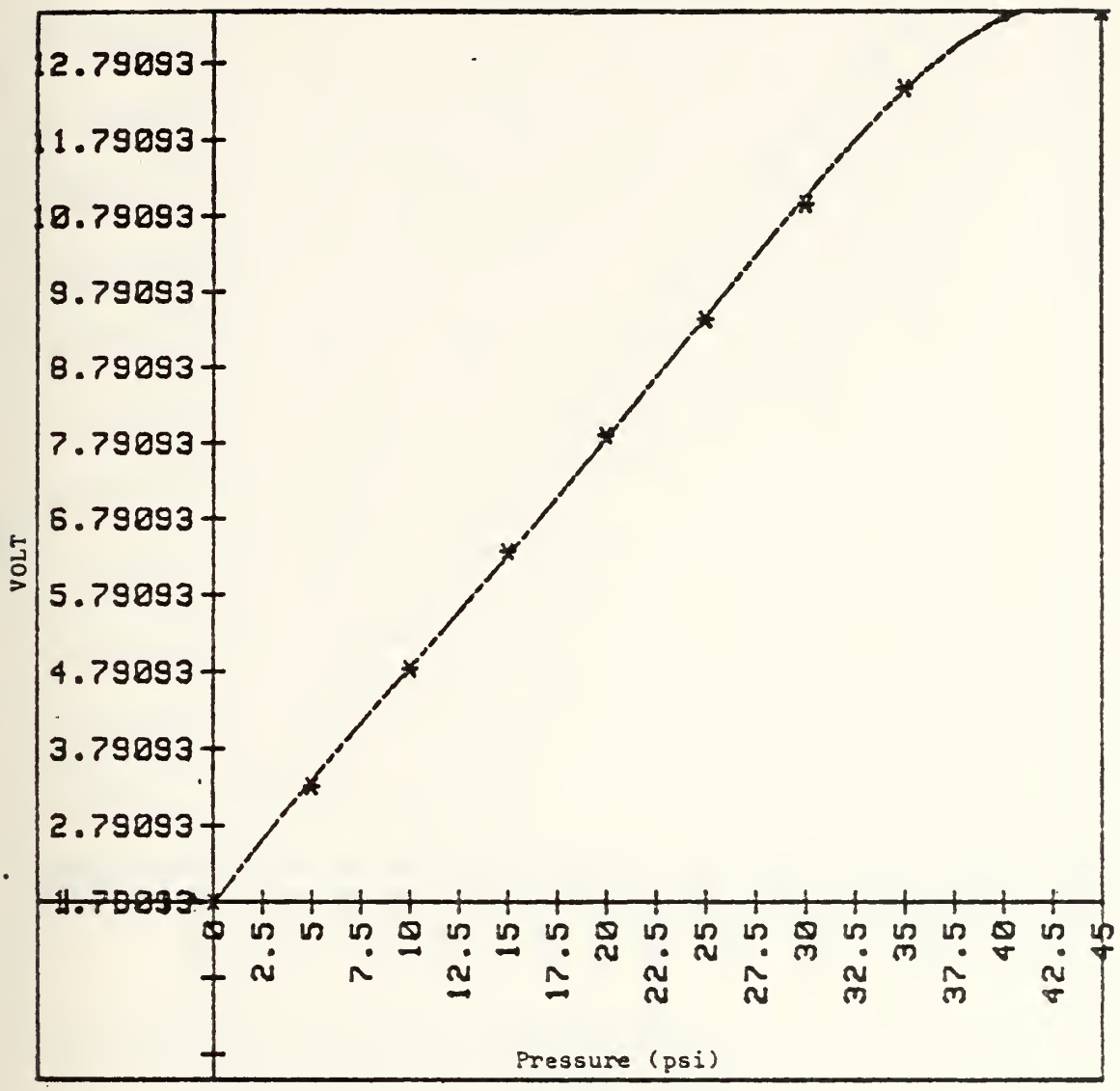
Calibration Plot of Pressure Transducer D



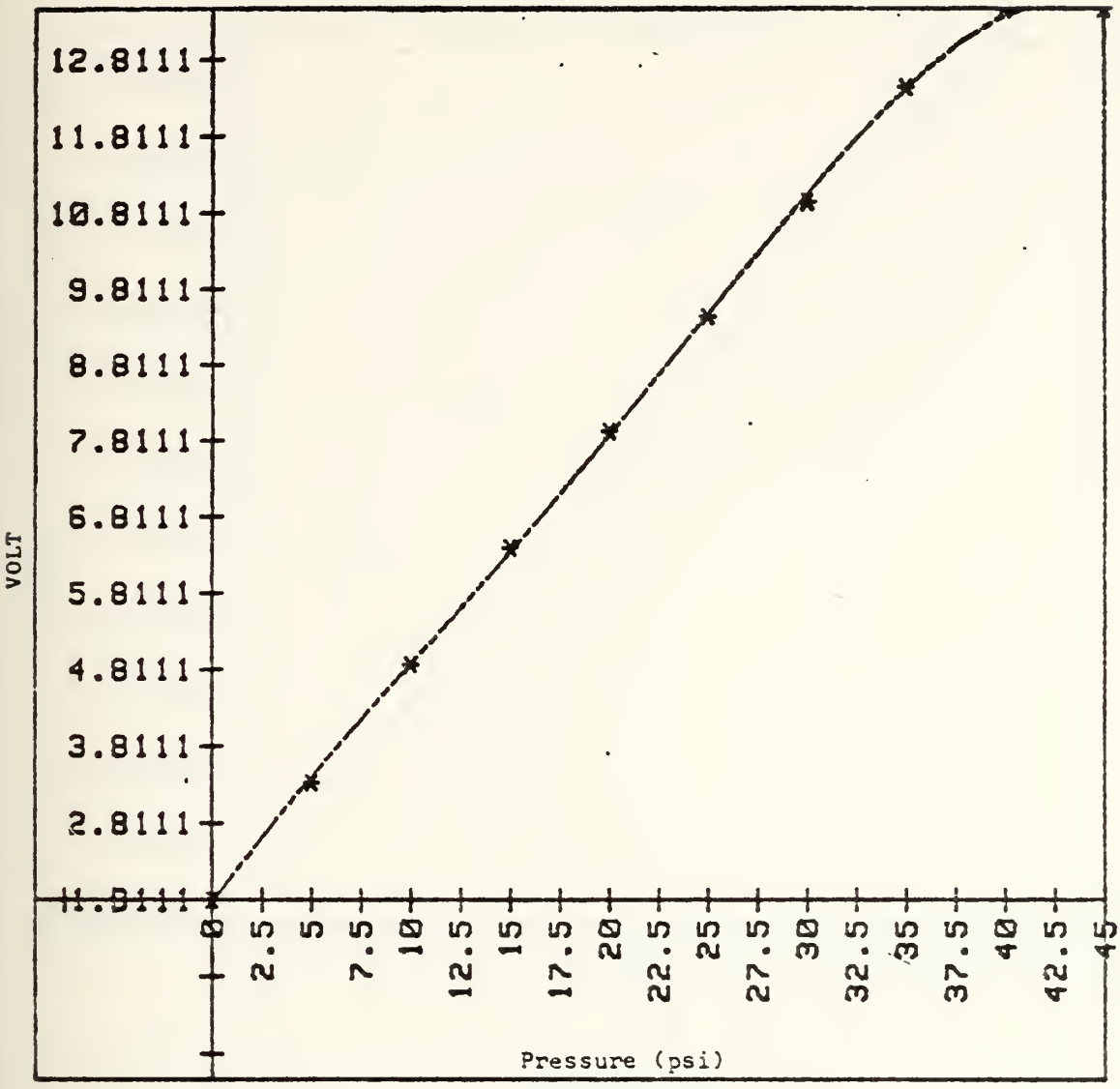
Calibration Plot of Pressure Transducer E



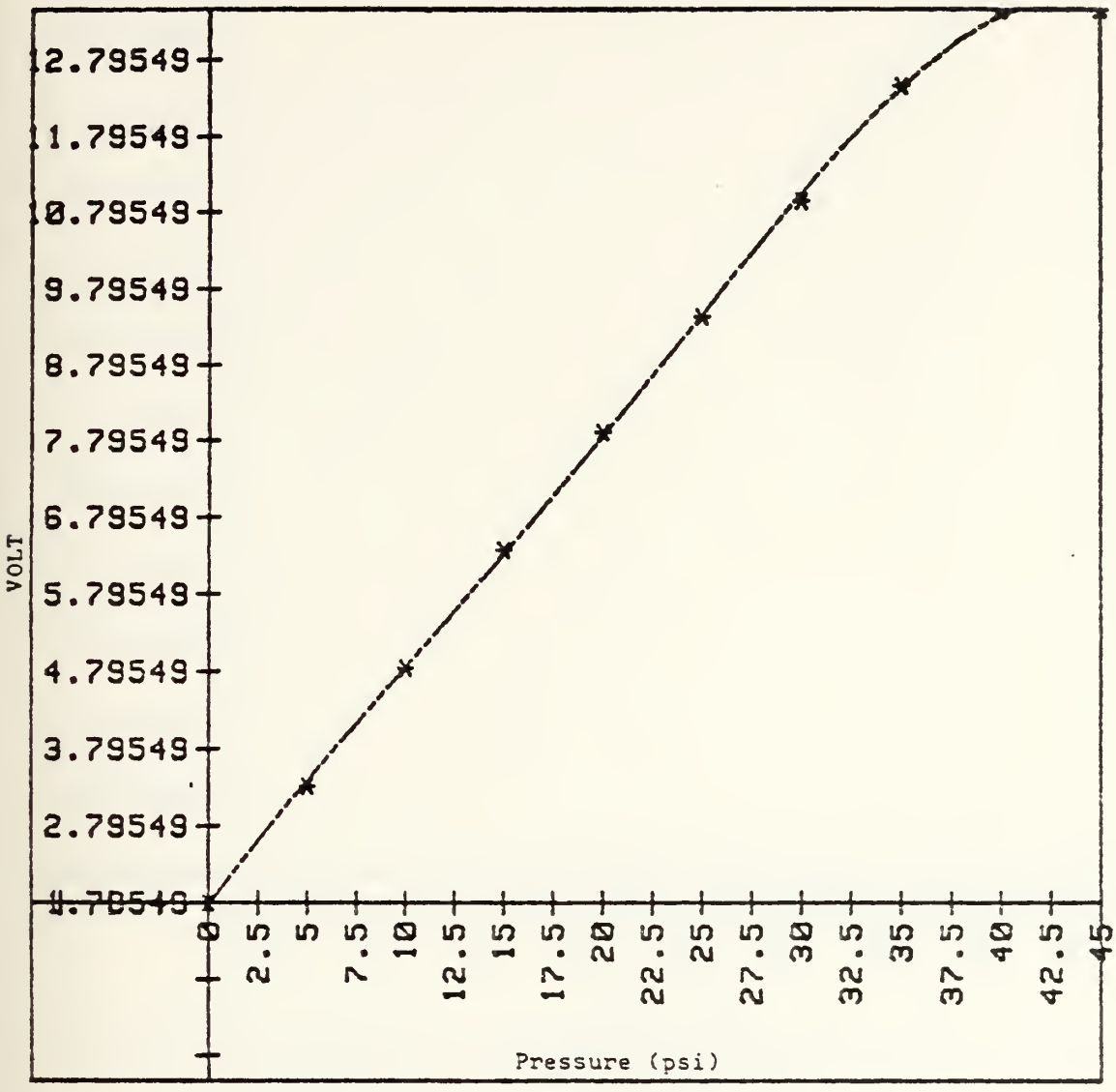
Calibration Plot of Pressure Transducer P



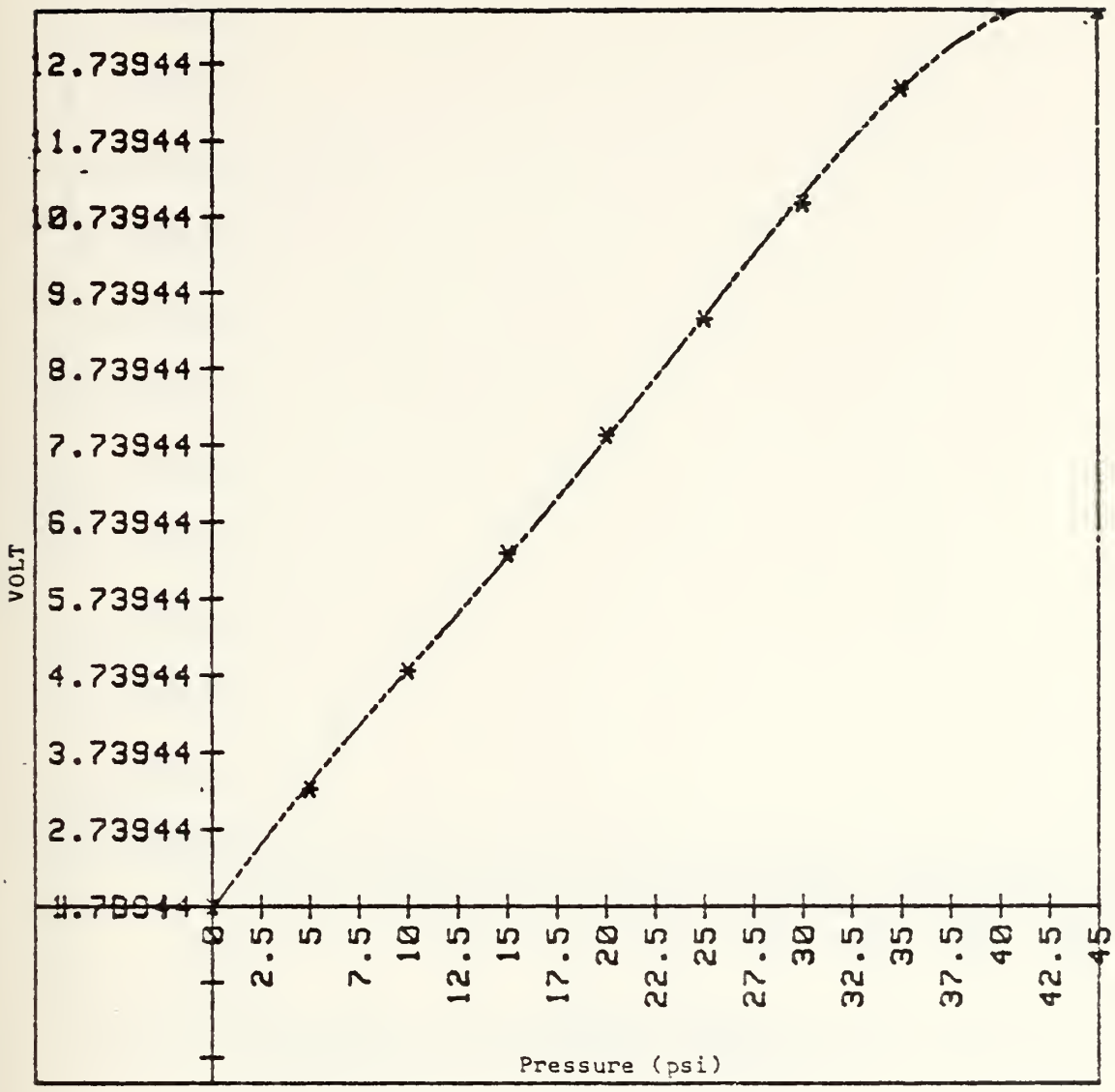
Calibration Plot of Pressure Transducer G



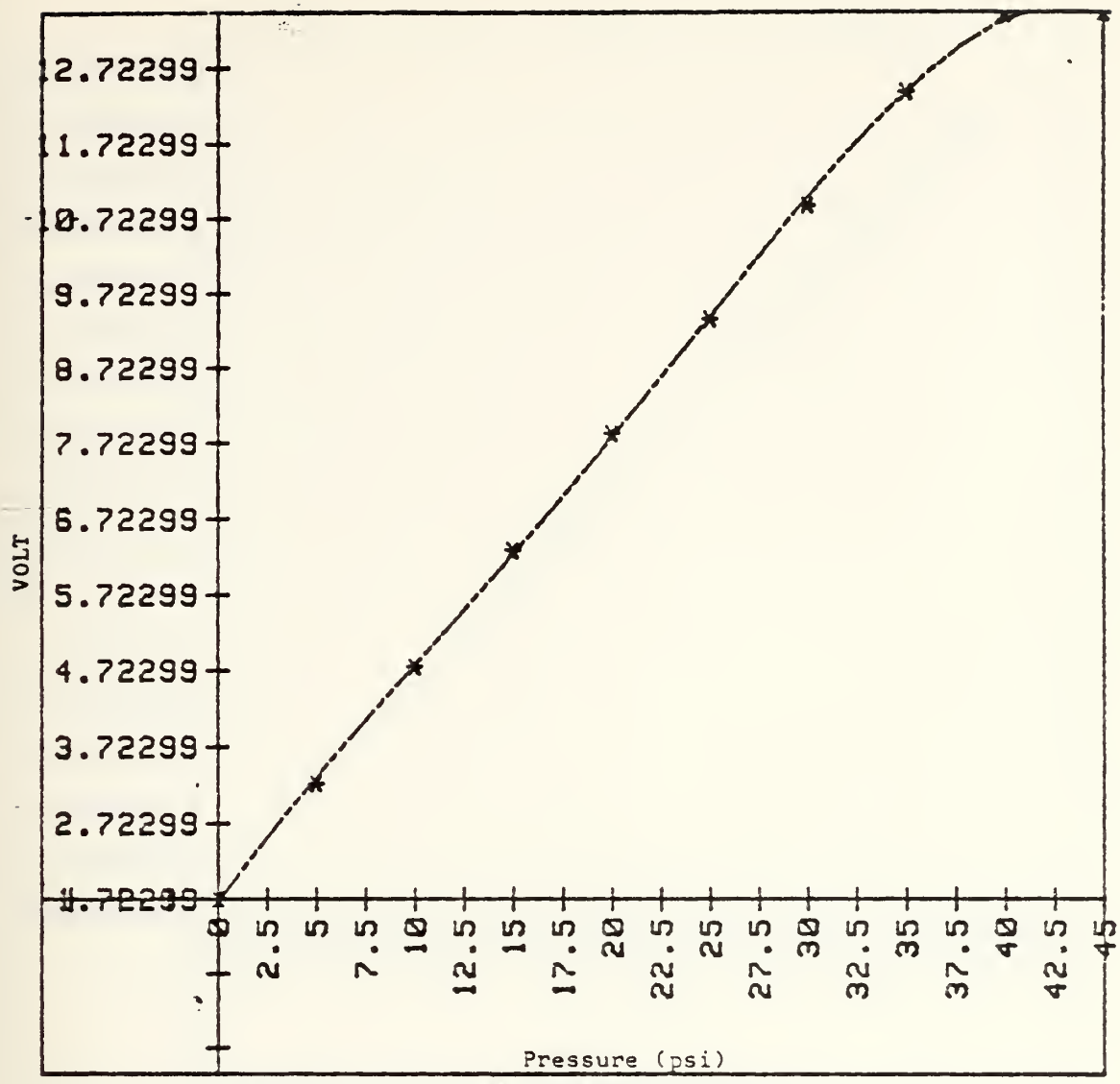
Calibration Plot of Pressure Transducer H



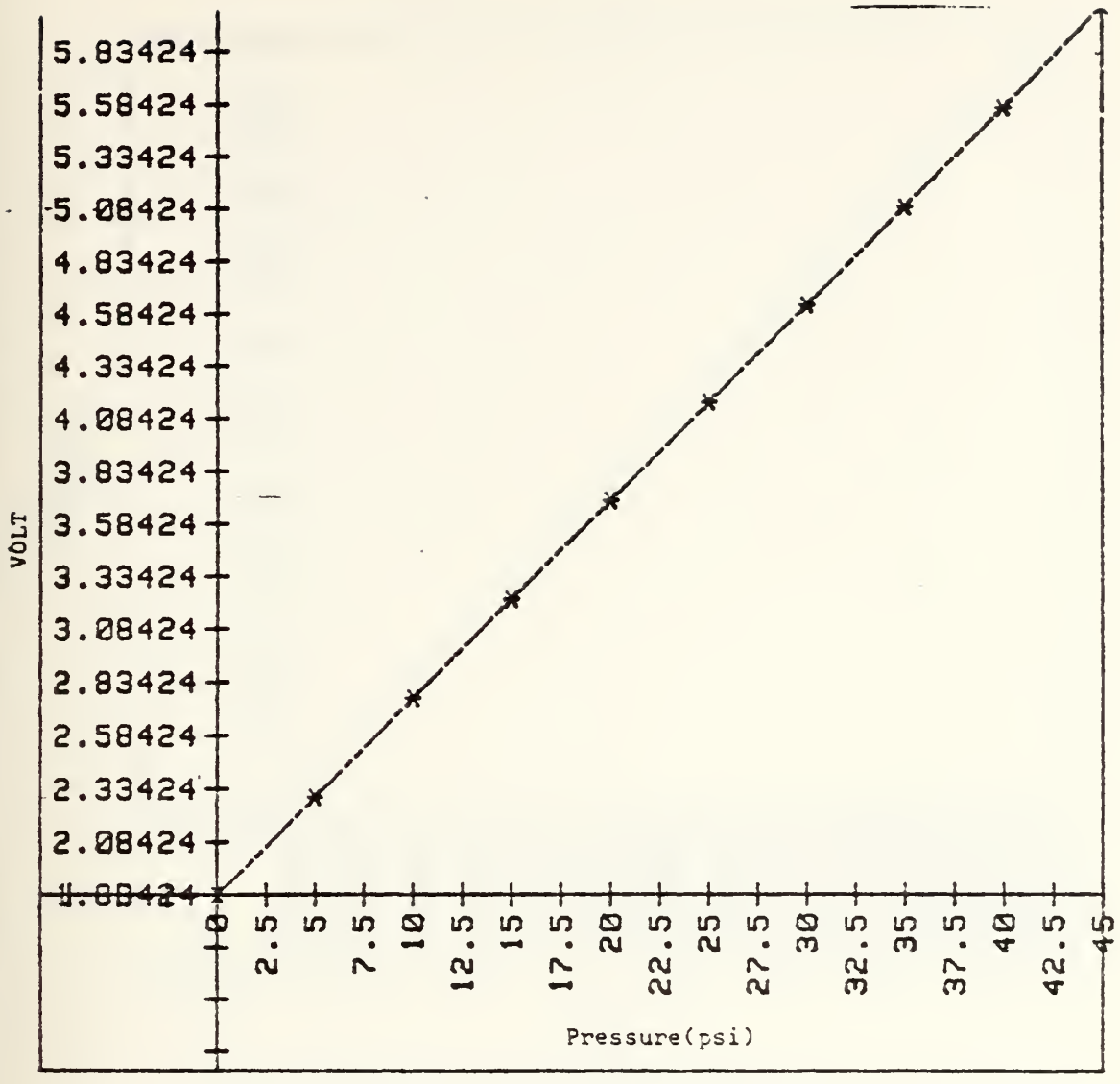
Calibration Plot of Pressure Transducer I



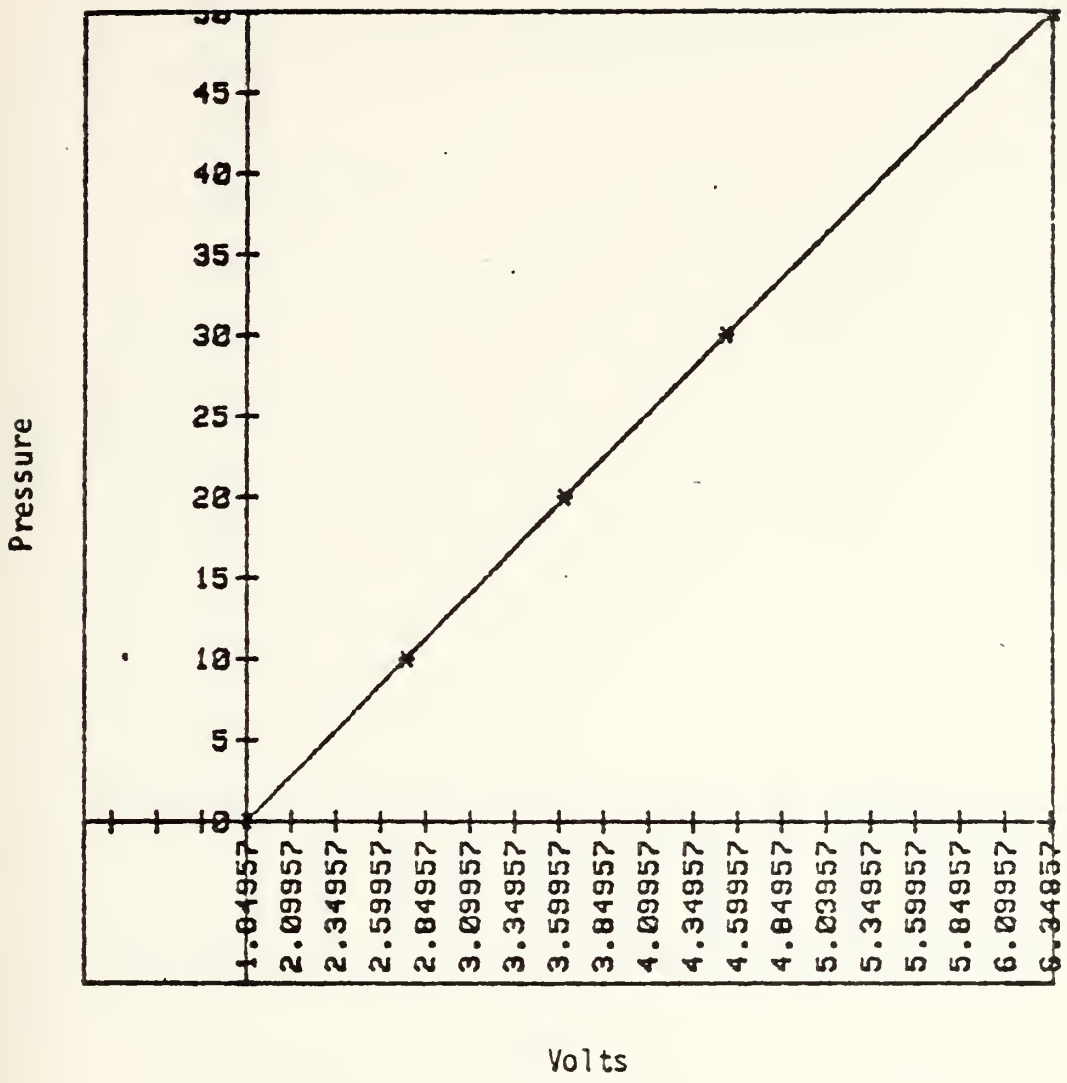
Calibration Plot of Pressure Transducer J



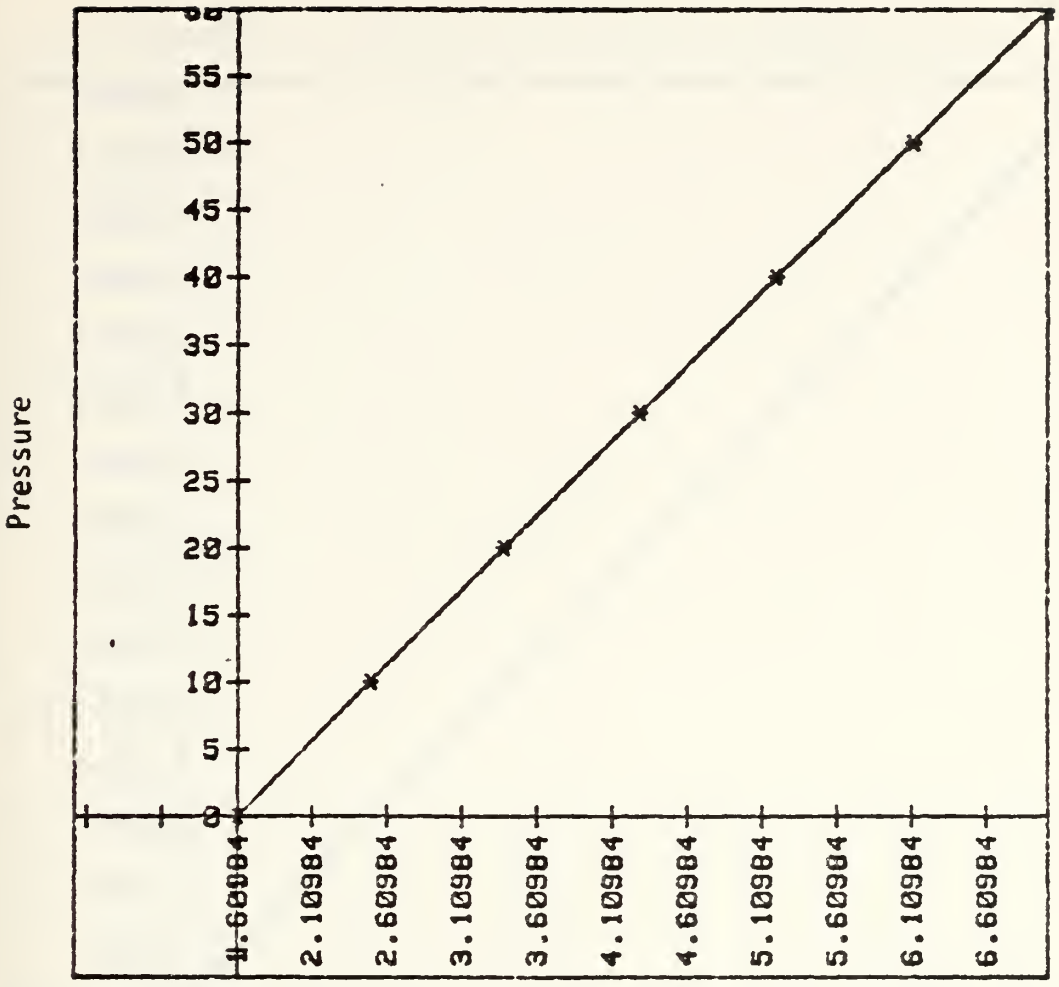
Calibration Plot of Pressure Transducer K



Calibration Plot of Pressure Transducer L

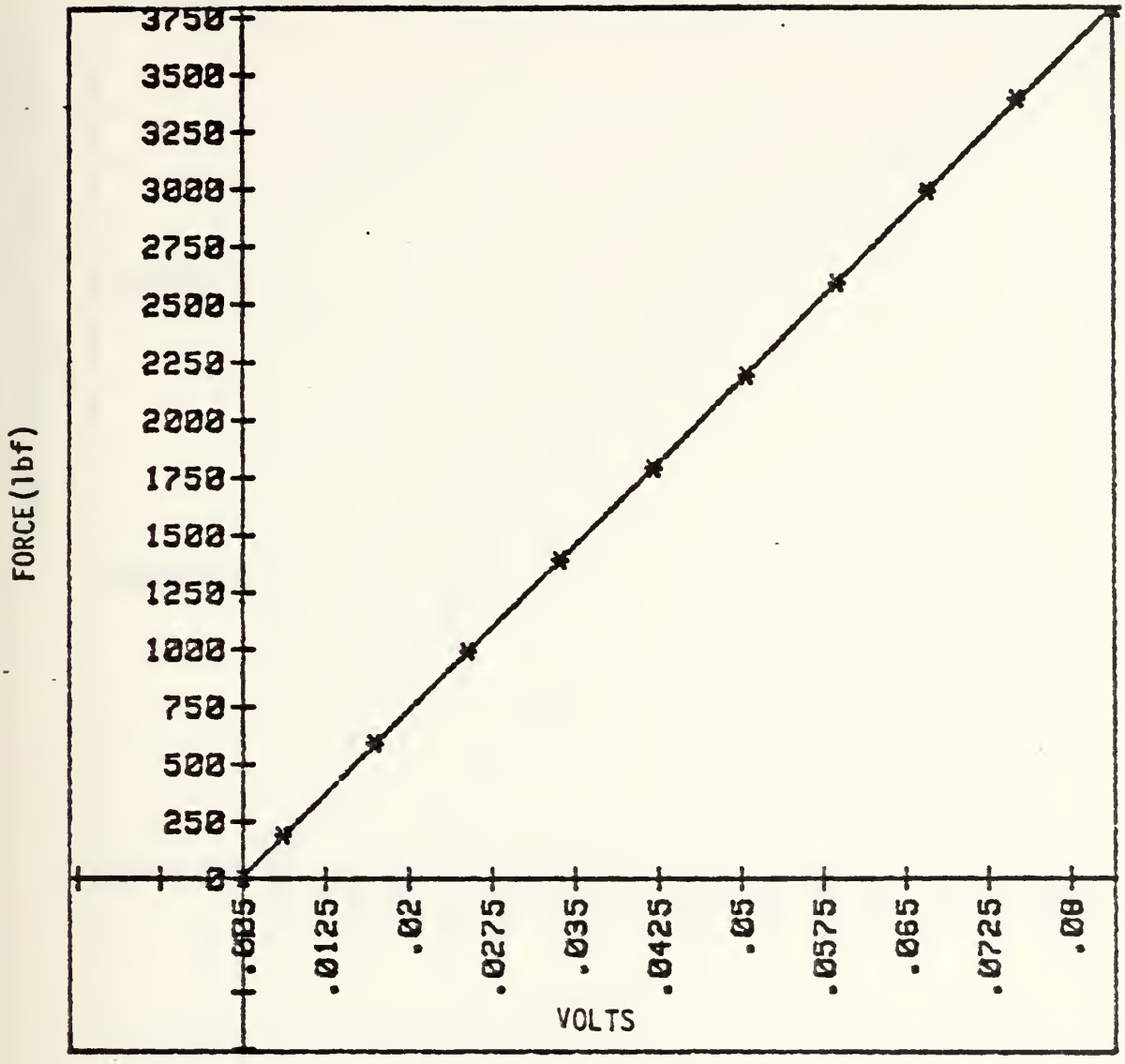


Calibration plot of pressure Transducer 0



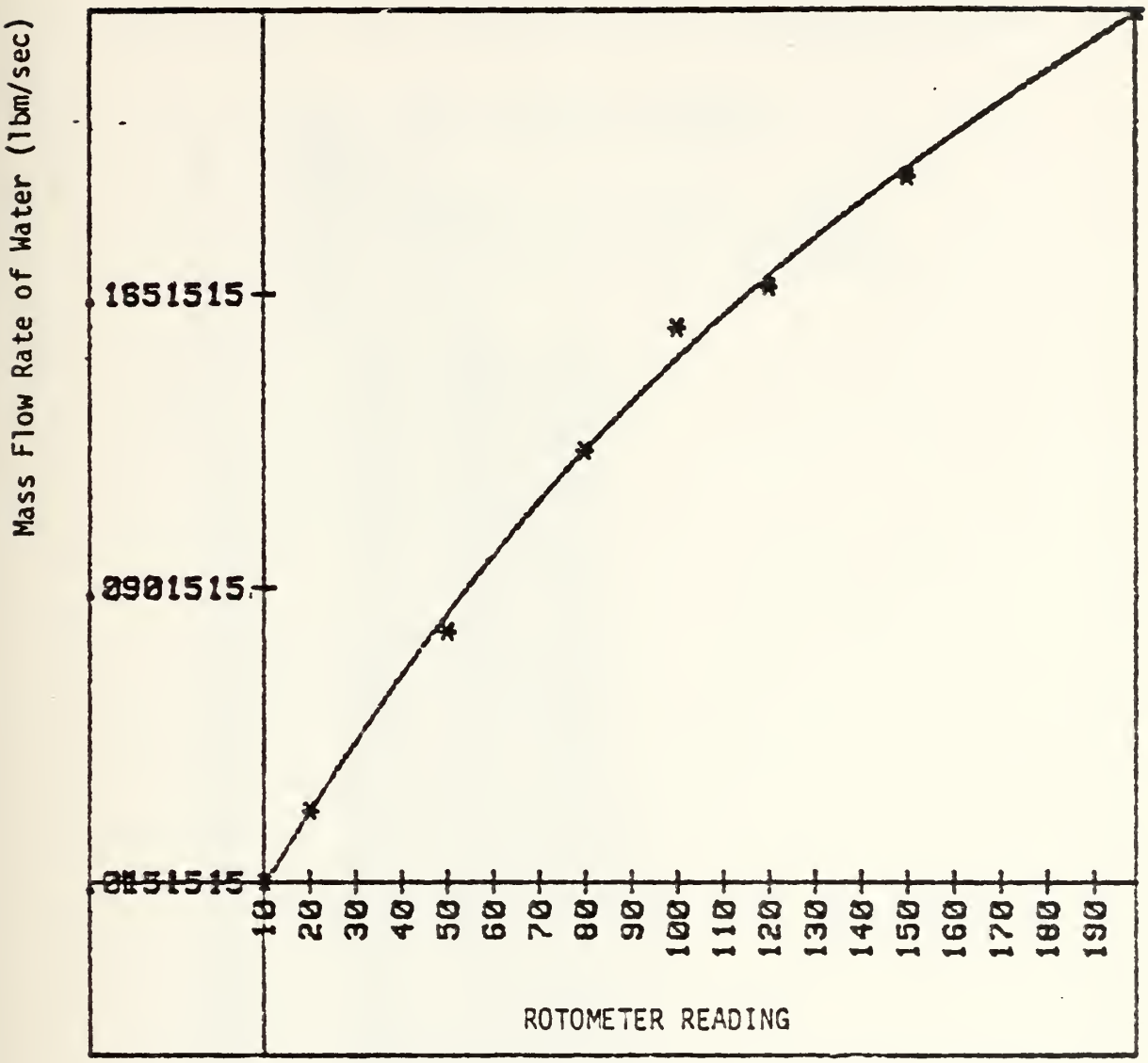
Calibration Plot of Pressure Transducer P

APPENDIX J: CALIBRATION PLOT FOR FORCE-BLOCK



Calibration Plot For Force-Block

APPENDIX K: CALIBRATION PLOT FOR ROTOMETER



Calibration Plot for Rotometer

APPENDIX L: DATA ACQUISITION AND ANALYSIS PROGRAM

```
3     PRINT "INPUT ROTOMETER READING"
4     INPUT Rr
5     PRINT Rr
7     DIM A(14),B(14),C(14),Dist(14),D(14)
8     DIM Press(14)
10    DIM X(18,100),Sum(18),Mean(18),Sum2(18)
30    N=10
40    FOR I=1 TO N
50       OUTPUT 709;"AI1VT1"
60       ENTER 709;X(1,I)
70       OUTPUT 709;"AI2VT1"
80       ENTER 709;X(2,I)
90       OUTPUT 709;"AI3VT1"
100      ENTER 709;X(3,I)
110      OUTPUT 709;"AI4VT1"
120      ENTER 709;X(4,I)
130      OUTPUT 709;"AI5VT1"
140      ENTER 709;X(5,I)
150      OUTPUT 709;"AI6VT1"
160      ENTER 709;X(6,I)
170      OUTPUT 709;"AI7VT1"
180      ENTER 709;X(7,I)
190      OUTPUT 709;"AI8VT1"
200      ENTER 709;X(8,I)
210      OUTPUT 709;"AI9VT1"
220      ENTER 709;X(9,I)
230      OUTPUT 709;"AI10VT1"
240      ENTER 709;X(10,I)
250      OUTPUT 709;"AI11VT1"
260      ENTER 709;X(11,I)
261      OUTPUT 709;"AI12VT1"
262      ENTER 709;X(12,I)
263      OUTPUT 709;"AI13VT1)"
264      ENTER 709;X(13,I)
265      OUTPUT 709;"AI14VT1)"
266      ENTER 709;X(14,I)
267      OUTPUT 709;"AI15VT1)"
268      ENTER 709;X(15,I)
270   NEXT I
440   FOR J=1 TO 16
450      Sum(J)=0
460      FOR I=1 TO N
470         Sum(J)=Sum(J)+X(J,I)
480      NEXT I
490      Mean(J)=Sum(J)/N
510   NEXT J
```

```
520   FOR I=1 TO 14
530   READ A(I),B(I),C(I),D(I),Dist(I)
540   DATA -6.049177,3.92593,-.17330131,.0112105,.5
550   DATA -7.059265,4.233834,-.2292065,.01415403,1.5
560   DATA -6.4905288,3.93412037,-.160249802,.009448598,2.5
570   DATA -7.05653853,4.69207328,-.341175732,.0189756532,3.5
580   DATA -7.00950749,4.15163753,-.207173977,.0123697788,4.5
590   DATA -6.38855694,3.93348997,-.160546739,.0095126941,5.5
600   DATA -6.58938462,3.95696947,-.164270383,.0096133938,6.5
610   DATA -6.587731,3.90750953,-.158062598,.0094269372,7.5
620   DATA -6.59491204,3.94889685,-.162699726,.009565139,8.5
630   DATA -6.35328646,3.92659595,-.165085722,.0099773509,9.5
640   DATA -6.20324295,3.84628939,-.146968664,.0088046866,10.5
650   DATA -20.2065629,11.1571691,-.0859126,.004917379,0
660   DATA -20.6682414,11.0677155,-.07562378,.011185984,0
670   DATA -18.8267355,11.9281137,-.17715903,.011005888,0
680   Press(I)=A(I)+B(I)*Mean(I)+C(I)*Mean(I)^2+D(I)*Mean(I)^3
681   Press(I)=Press(I)+14.696
690   NEXT I
```

```
700   Fb=1/453.6*(-234.396482+48715.7753*Mean(15)-11261.538*Mean(15)^2+33899.3*M
ean(15)^3)
710   Mwater=-.0063268+.002097278*Rr-.00000658*Rr^2+.000000011*Rr^3
720   Fn=Fb*22.5/22.0
730   Dw=.920/12
740   Dd=3/12
750   E=1/(1-Dw/Dd)
760   Dp=Mean(14)-Mean(13)
770   Cc=.62
771   K=Cc*E
772   Aa=3.1416*Dw^2/4
774   Y=1-(.41+.35*(Dw/Dd)^4*(Dp/(1.4*Mean(14))))
780   Gc=32.2
790   Den=.076297*Mean(12)/14.696
800   Mair=K*Aa*Y*SQR(2*Gc*Den*Dp*144)
810   Mtotal=Mair+Mwater
820   Vexit=Fn/(Mtotal)*32.2
830   PRINT
840   PRINT "PRESSURE AS A FUNCTION OF DISTANCE"
850   PRINT "_____________________________________"
860   PRINT "DISTANCE(X)","PRESSURE"
870   PRINT "_____________________"
880   FOR I=1 TO 14
890   PRINT Dist(I),Press(I)
900   NEXT I
910   PRINT "MASS FLOW RATE OF WATER =";Mwater;"LBM/SEC"
920   PRINT "MASS FLOW RATE OF AIR   =";Mair;"LBM/SEC"
930   PRINT "TOTAL MASS FLOW RATE    =";Mtotal;"LBM/SEC"
940   PRINT "THRUST                  =";Fn;"LBF"
950   PRINT "MIXTURE RATIO           =";Mwater/Mair
960   PRINT "EXIT VELOCITY           =";Vexit;"FT/SEC"
970   PRINT "INLET PRESSURE          =";Press(12);"PSI"
980   END
```

INPUT ROTOMETER READING
 0

PRESSURE AS A FUNCTION OF DISTANCE

DISTANCE(X)	PRESSURE
.5	14.5598137417
1.5	14.4607948757
2.5	14.4788575371
3.5	14.4188520649
4.5	14.4711792506
5.5	14.5553698274
6.5	14.4532490549
7.5	14.4461409662
8.5	14.5336111051
9.5	14.5262956477
10.5	14.5245848183
0	14.1098474897
0	11.8981971096
0	17.6235437008

MASS FLOW RATE OF WATER =-.0063268 LBM/SEC
MASS FLOW RATE OF AIR = .0110711550501 LBM/SEC
TOTAL MASS FLOW RATE = .00474435505015 LBM/SEC
THRUST = 1.76920486692 LBF
MIXTURE RATIO =-.571467021403
EXIT VELOCITY = 12007.6166544 FT/SEC
INLET PRESSURE = 14.1098474897 PSI

APPENDIX M: DUAL-PHASE TWO-COMPONENT COMPUTER PROGRAM

```
$JOB
C*****************************************************
C     REAL TWO-PHASE TWO-COMPONENT NOZZLE FLOW        *
C     MODIFIED FOR USE AT NAVAL POSTGRADUATE SCHOOL   *
C     PROF. J.SLADKY AND  LT. T.C.MOLLIE              *
C*****************************************************
      COMMON IZZZAY
      DIMENSION IZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTOP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
     1          ALPHS   , AM      , AP      , AR      , AT      , BA      ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
     4    CBG1  , CAL   , CASE    , CBGMB   , CBG     , CBLMB   , CBL     ,
      COMMON    CDMG    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
     6          CFOMS   , CGMB    , CGB     , CG4S    , CL4B    , CL4     ,
     7          CL4S    , CSAVE   , D       , D2      , DA      , DAFF    ,
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2   ,
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DENT    ,
     1          DESIS   , DESOS   , DO      , DP1     , DP      , DRAY    ,
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSTES1  , DSTES2  ,
     4          DSRPS   , DS      , DSX1    , DSY2    , DTG1    , DTGB    ,
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DY1     ,
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMBGB   ,
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,
     9          EML     , EMLS    , EMT     , ESQ     , FLAGP   , FUX     ,
      COMMON    H       , HJI     , HKAG    , HKBG    , HKGM1   , HKGM2   ,
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,
     2          HLB1    , HLBM    , HLB     , HLMS    , HM      , HMS     ,
     3          HOPE    , HT      , IACV    , IBLM    , IBLK    , IBM     ,
     4          IJH     , INT     , ISET    , IZERO   , K       , K1      ,
      COMMON    K2      , KA2     , KDSCT   , KDS     , KL      , KM1     ,
     6          KP      , KTSCT   , KTB     , KXB1    , KXP     , L       ,
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPSCT   ,
     8          LSM     , MBU     , MFSQ    , MFP     , MGBO    , MM      ,
     9    M     , MOP   , MTHT    , NACV    , NB      , NCLK    , NCS5    ,
      COMMON    NDIAG   , NDS     , NGS     , NIB     , NIS     , NLST    ,
     1          NNA     , NNB     , NNDS    , NNN     , NNO     , NN      ,
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,
     4          PAS     , PBB     , PBMB    , PBOB    , PBO     , PB      ,
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,
     6          PL1     , PO      , PS      , PT      , Q       , QIB     ,
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,
     8          RC      , RDELIM  , RDFION  , RDLMS   , RDOMS   , RFF     ,
     9          RFM     , RFMS    , RGSLIM  , RGSO    , RHBSZ   , RHOGB
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,
     2          RGBL    , ROM     , RO      , R       , RSLIM   , RS      ,
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,
     4          S3      , S4      , SA      , SB      , SGN     , SIG     ,
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,
     7          SOP     , SO      , SOS     , SS      , SZM     , SZO     ,
     8          T       , TB      , TBRAY   , TBRAY1  , TEMB    , TFO     ,
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS    ,
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKF     ,
     1          TLMB    , TLO     , TL      , TLS     , TOT     , TWIM    ,
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAB     ,
     3          VBD     , VBDS    , VBX     , VBXSQ   , VB      , VBSO    ,
     4          VBS     , VGO     , VG      , VGSO    , VGS     , VIAG    ,
      COMMON    VIALB   , VIAL    , VIBG    , VIBLD   , VIBL    , VIBM    ,
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,
     7          VL      , VLSO    , VLS     , VS      , VSS     , VXGB    ,
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBLS    ,
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,
     1          XINT    , XP      , XS      , XX      , XXA     , Y1      ,
```

```
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT                    MAIN0860
      DIMENSION PL(10)                                                          MAIN0870
      DIMENSION NDRAY(75)                                                       MAIN0880
      DIMENSION DATE(5),CASE(3),OID(8),XP(2,75),PL1(10),                        MAIN0890
     1      C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TDRAY       MAIN0900
     21(100),DRAY(75),HT(16),DINT(8)                                            MAIN0910
      EQUIVALENCE (NDRAY(1),DRAY(1))                                            MAIN0920
      XX=-1.0                                                                   MAIN0930
      SMIN = 1.0E-6                                                             MAIN0940
      IZERO = 0                                                                 MAIN0950
      ISET = 75                                                                 MAIN0960
      DINT(1)=.5                                                                MAIN0970
      DINT(2)=.1                                                                MAIN0980
      DINT(3)=.01                                                               MAIN0990
      DINT(4)=.001                                                              MAIN1000
      DINT(5)=.0001                                                             MAIN1010
      DINT(6)=.00001                                                            MAIN1020
      DINT(7)=.000001                                                           MAIN1030
      DINT(8)=.0000001                                                          MAIN1040
      CALL ADATA
C                                                                               MAIN1230
C INITIALIZE TABLE TAPE, BRING IN PERMANENT TABLES (ONE-DIMENSIONAL),           MAIN1240
C    FILL ARRAY INDICATING TEMPERATURES INCLUDED IN TWO                         MAIN1250
C    DIMENSIONAL TABLES, INITIALIZE PAGE COUNT.                                 MAIN1260
C                                                                               MAIN1270
    5 LPGCT=1                                                                   MAIN1280
      CALL TABLE                                                                MAIN1290
      CALL INTERP(VAR,0,T,P)                                                    MAIN1300
C     ACTIVATE THE FOLLOWING CARD TO GET A PRINTOUT OF THE PROPERTIES
C     CALL INTERP(VAR,20,T,P)                                                   MAIN1310
      NSTMT=999                                                                 MAIN1320
  100 CONTINUE                                                                  MAIN1330
      CALL SECT1                                                                MAIN1340
      IF(NSTMT-5)999,5,101                                                      MAIN1350
  101 CONTINUE                                                                  MAIN1360
      IF(NSTMT-99)999,99,200                                                    MAIN1370
  999 CALL DUMP                                                                 MAIN1380
  200 CONTINUE                                                                  MAIN1390
      CALL SECT2                                                                MAIN1400
      IF(NSTMT-40)999,300,201                                                   MAIN1410
  201 IF(NSTMT-50)999,300,202                                                   MAIN1420
  202 IF(NSTMT-60)999,400,203                                                   MAIN1430
  203 IF(NSTMT-110)999,700,999                                                  MAIN1440
  300 CONTINUE                                                                  MAIN1450
      CALL SECT3                                                                MAIN1460
      IF(NSTMT-30)999,200,301                                                   MAIN1470
  301 IF(NSTMT-70)999,500,302                                                   MAIN1480
  302 IF(NSTMT-110)999,700,103                                                  MAIN1490
  303 IF(NSTMT-145)999,200,104                                                  MAIN1500
  304 IF(NSTMT-161)999,200,305                                                  MAIN1510
  305 IF(NSTMT-1142)999,200,999                                                 MAIN1520
  400 CONTINUE                                                                  MAIN1530
      CALL SECT4                                                                MAIN1540
      IF(NSTMT-30)999,200,401                                                   MAIN1550
  401 IF(NSTMT-110)999,700,402                                                  MAIN1560
  402 IF(NSTMT-140)999,600,403                                                  MAIN1570
  403 IF(NSTMT-161)999,200,999                                                  MAIN1580
  500 CONTINUE                                                                  MAIN1590
      CALL SECT5                                                                MAIN1600
      IF(NSTMT-30)999,200,501                                                   MAIN1610
  501 IF(NSTMT-110)999,700,502                                                  MAIN1620
  502 IF(NSTMT-2399)999,600,999                                                 MAIN1630
  600 CONTINUE                                                                  MAIN1640
      CALL SECT6                                                                MAIN1650
      IF(NSTMT-100)999,500,601                                                  MAIN1660
  601 IF(NSTMT-110)999,700,6020                                                 MAIN1670
 6020 IF(NSTMT-520)999,800,602                                                  MAIN1680
  602 IF(NSTMT-1490)999,500,999                                                 MAIN1690
  700 CONTINUE                                                                  MAIN1700
      CALL THRCAT                                                               MAIN1710
      IF(NSTMT-497)999,800,999                                                  MAIN1720
  800 CONTINUE                                                                  MAIN1730
```

```
      CALL DIAGNO                                                       MAIN1740
      IF(NSTMT-10)999,100,801                                           MAIN1750
  801 IF(NSTMT-63)999,400,999                                           MAIN1760
C                                                                       MAIN1770
C     LAST CASE JUST COMPLETED.   PRINT OUT ALL INPUT TABLES            MAIN1780
C       AND TERMINATE PROCESSING.                                       MAIN1790
   99 T=LPGCT                                                           MAIN1800
      CALL INTRP(VAR,20,T,P)                                            MAIN1810
      WRITE (6,9001)                                                    MAIN1820
      STOP                                                              MAIN1830
 9001 FORMAT(1H1 ,14HMAIN STATION 1   )                                 MAIN1840
      END                                                               MAIN1850
                     SUBROUTINE SECT1                                   SEC10010
      COMMON TZZZAY                                                     SEC10020
      DIMENSION TZZZAY(11200)                                           SEC10030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP            SEC10040
C     IT MUST BE THE FIRST COMMON BLOCK                                 SEC10050
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB ,  SEC10070
     1          ALPHS   , AM      , AP      , AS      , AT      , BA       ,  SEC10080
     2          BB      , BETAB   , BETAMB  , BRIA    , BETAS   , BM       ,  SEC10090
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB    ,  SEC10100
     4  CBG1    , CAL   , CASS    , CBGMB   , CBG     , CBLMB   , CBL      ,  SEC10110
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFDM     ,  SEC10120
     6          CFDMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM      ,  SEC10130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DACE     ,  SEC10140
     8          DD      , DELIM   , DELI    , DELIS   , DELDM   , DELD     ,  SEC10150
     9          DELDS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2    ,  SEC10160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT     ,  SEC10170
     1          DLSIS   , DLSOS   , DO      , DP1     , D2      , DRAY     ,  SEC10180
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM    ,  SEC10190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2   ,  SEC10200
     4          DSRES   , DS      , DSA1    , DSX2    , DTG1    , DTGB     ,  SEC10210
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL      ,  SEC10220
     6          DT      , DVDSQ   , DVGSQ   , DVLSQ   , DX      , DYI      ,  SEC10230
     7          DYD     , ED      , EDS     , EMAGS   , EMAG    , EMBGB    ,  SEC10240
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM     ,  SEC10250
     9          EML     , EMLS    , EMI     , FGO     , FLEDP   , FUX      ,  SEC10260
      COMMON    H       , HJI     , HKAG    , HKGG    , HKGM1   , HKGM2    ,  SEC10270
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS     ,  SEC10280
     2          HLB1    , HLEM    , HLB     , HLBS    , HM      , HMS      ,  SEC10290
     3          HOPP    , HT      , IACV    , IBLM    , IBLK    , IBM      ,  SEC10300
     4          IJK     , INT     , ISRT    , IZERO   , K       , A1       ,  SEC10310
      COMMON    K2      , KAD     , KDSCT   , KDS     , KL      , KB1      ,  SEC10320
     6          KR      , KTOCT   , KTB     , KXP1    , KXP     , L        ,  SEC10330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT    ,  SEC10340
     8          LSM     , MAB     , MPDO    , MPP     , MGPO    , MM       ,  SEC10350
     9  M       , MOP   , MTHT    , NACV    , NB      , NCLK    , NCSS     ,  SEC10360
      COMMON    NDIAG   , NDS     , NGG     , NTB     , NTS     , NLST     ,  SEC10370
     1          NMA     , NNB     , NNDS    , NXN     , NEP     , NN       ,  SEC10380
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS       ,  SEC10390
     3          P       , P10     , P11     , PAB     , PAMB    , PA       ,  SEC10400
     4          PAS     , PBB     , PBMB    , PBOB    , PBO     , PB       ,  SEC10410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL       ,  SEC10420
     6          PL1     , PO      , PS      , PT      , Q       , QID      ,  SEC10430
     7          R1      , RA      , RAG     , RAXO    , RAX     , RB       ,  SEC10440
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , RE       ,  SEC10450
     9          REM     , RGMS    , RBSLIM  , RBSO    , RBSZ    , RHOGB    ,  SEC10460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS    ,  SEC10470
     1          RIM     , RL      , RM      , ROALB   , ROAL    , ROBLB    ,  SEC10480
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS       ,  SEC10490
     3          RVB     , RV      , RVS     , S       , S1      , S2       ,  SEC10500
     4          S3      , S4      , SA      , SB      , SGN     , SIG      ,  SEC10510
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLO     ,  SEC10520
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2     ,  SEC10530
     7          SOP     , SO      , SOJM    , SS      , SSP     , SSO      ,  SEC10540
     8          SSS     , TB      , TBRAY   , TBRAY1  , TEMB    , TGO      ,  SEC10550
     9          TG      , TGS     , THIM    , THIO    , THI     , THETG    ,  SEC10560
      COMMON    THOM    , THSO    , THO     , THOS    , TK      , TKP      ,  SEC10570
     1          TLMB    , TLO     , TL      , TLS     , TSP     , TSLM     ,  SEC10580
     2          TMOMS   , TMOM    , TMOMS   , V1      , V2      , VAB      ,  SEC10590
     3          VBD     , VBDS    , VBM     , VBMSQ   , VB      , VBSO     ,  SEC10600
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG     ,  SEC10610
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      COMMON    VIALB   , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,      SEC10620
     6          VIGMS   , VILB   , VILM   , VILMS  , VLM    , VLO    ,      SEC10630
     7          VL      , VLSQ   , VLS    , VS     , VSS    , WAGB   ,      SEC10640
     8          WAG     , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,      SEC10650
     9          WBL     , WGB    , WG     , WGS    , WIM    , WIMS   ,      SEC10660
      COMMON    WOM     , WOMS   , X      , X10    , X11    , XCLK   ,      SEC10670
     1          XINT    , XP     , XS     , XX     , XXA    , YI     ,      SEC10680
     2          YIS     , YO     , YOS    , ZZZ    , NSTMT                  SEC10690
      DIMENSION PL(10)                                                      SEC10700
       DIMENSION NDRAY(75)                                                  SEC10710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                    SEC10720
     1      C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAYSEC10730
     21(100),DRAY(75),HT(18),DIST(8)                                        SEC10740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                        SEC10750
C     ************************************************************      SEC10760
C     ************** STATEMENT NO. 10 ****************************      SEC10770
C     ************************************************************      SEC10780
   10 CONTINUE                                                            SEC10790
      NSTMT=9999                                                          SEC10800
C     DO WE HAVE TO NOT  (XX=-1.0 IN MAIN)  SET (POSSIBLY) IN SECT4       SEC10810
      IF(XX+1.0)1,2,1                                                     SEC10820
    1 CONTINUE                                                            SEC10830
      WRITE (6,8077) XX                                                   SEC10840
      XX=-1.0                                                             SEC10850
    2 CONTINUE                                                            SEC10860
C READ INPUTS AND PRINT HEADING FOR THIS CASE                             SEC10870
      READ (5,910,END=7777) (DATE(I),I=1,5),(CASE(I),I=1,3),(QID(I),      SEC10880
     1I=1,8),NS,NP                                                        SEC10890
      IF(NS)5,99,11                                                       SEC10900
   99 NSTMT=99                                                            SEC10910
      RETURN                                                              SEC10920
   11 CONTINUE                                                            SEC10930
      READ (5,911) MBU,MOP,MGEO,NDS,NSO,NB,NNS                            SEC10940
      READ (5,912) DP,EC,PHI,RAXO,EMT,H,ALAM,DP1,                         SEC10950
     1WAL,WBL,SA,SB,DO,PO,TGO,TLO,VGO,VLO,THOO,THIO,EDS,ESO,              SEC10960
     2EB                                                                  SEC10970
      WRITE (6,913) DATE,CASE,QID,NS,NP,                                  SEC10980
     1MBU,MOP,    MGEO,NDS,NSO,NB,    NNS,DP,EC,PHI,RAXO,EMT,            SEC10990
     2H,ALAM,WAL,WBL,SA,SB,DO,PO,TGO,TLO                                  SEC11000
      WRITE (6,9913) VGO,VLO,THOO,THIO,EDS,ESO,EB,DP1                     SEC11010
      NDIAG=0                                                             SEC11020
      NNN=0                                                               SEC11030
      KAD=1                                                               SEC11040
      NACV = 0                                                            SEC11050
      MM=0                                                                SEC11060
      IACV = 0                                                            SEC11070
      KTB = 1                                                             SEC11080
      KDS = 1                                                             SEC11090
       LCT2=0                                                             SEC11100
      K1=1                                                                SEC11110
      K2=1                                                                SEC11120
      KDSCT=0                                                             SEC11130
      KTBCT=0                                                             SEC11140
      NCT6=0                                                              SEC11150
      LCT1=30                                                             SEC11160
      K=1                                                                 SEC11170
C                                                                         SEC11180
C  GET X(P) TABLE IDENTIFICATION AND X(P) TABLE DATA POINTS.              SEC11190
C                                                                         SEC11200
      IF(MOP)1360,14,1360                                                 SEC11210
   14 READ (5,9914)  (XXA(I),I=1,8)                                       SEC11220
      WRITE (6,9915)  (XXA(I),I=1,8)                                      SEC11230
C                                                                         SEC11240
C READ IN X(P) TABLE IF MOP=0                                             SEC11250
      DO 8000 KP=1,75                                                     SEC11260
      DO 8000 JP=1,2                                                      SEC11270
      XP(JP,KP)=-1.0                                                      SEC11280
 8000 CONTINUE                                                            SEC11290
C                                                                         SEC11300
    9 READ (5,914) (C(L),L=1,6)                                           SEC11310
      DO 1320 L=1,5,2                                                     SEC11320
      IF(C(L)-C(L+1))18,15,18                                             SEC11330
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   15 IF(C(L) - 100000.)18,9916,18                                          SEC11400
   18 XP(1,K)=C(L)                                                          SEC11410
      XP(2,K)=C(L+1)                                                        SEC11420
      IF(K-ISET)19,19,21                                                    SEC11430
   19 K=K+1                                                                 SEC11440
 1320 CONTINUE                                                              SEC11450
      GO TO 9                                                               SEC11460
 9916 K = K-1                                                               SEC11470
C       THIS IS A FIX FOR PRESSURE TABLE INTERP AT STEP 51    JHH      7/08/SEC11480
      KXP1 = K                                                              SEC11490
C                                                                           SEC11500
C PRINTOUT X(P) TABLE JUST READ IN                                          SEC11510
C                                                                           SEC11520
      L1=1                                                                  SEC11530
      L2=8                                                                  SEC11540
      WRITE (6,915)                                                         SEC11550
   16 WRITE (6,903) (XP(1,LT),LT=L1,L2)                                     SEC11560
      WRITE (6,917) (XP(2,LT),LT=L1,L2)                                     SEC11570
      LCT1=LCT1+3                                                           SEC11580
      IF(L2-K) 13,22,22                                                     SEC11590
   13 L1=L1+8                                                               SEC11600
      L2=AMIN0(L2+8,K)                                                      SEC11610
      IF(LCT1-52)16,17,17                                                   SEC11620
C                                                                           SEC11630
C MAXIMUM LINE COUNT EXCEEDED - START NEW PAGE.                             SEC11640
C                                                                           SEC11650
   17 WRITE (6,918) LPGCT                                                   SEC11660
      LCT1=4                                                                SEC11670
      LPGCT=LPGCT+1                                                         SEC11680
      GO TO 16                                                              SEC11690
C                                                                           SEC11700
C X(P) TABLE LIMITS EXCEEDED - PRINT ERROR MESSAGE AND                      SEC11710
C     EXIT TO NEXT CASE.                                                    SEC11720
C                                                                           SEC11730
   21 WRITE (6,921)                                                         SEC11740
      GO TO 10                                                              SEC11750
C                                                                           SEC11760
   22 CONTINUE                                                              SEC11770
C                                                                           SEC11780
C APPROPRIATE TABLES HAVE BEEN READ IN AS REQUIRED                          SEC11790
C                                                                           SEC11800
 1360 CONTINUE                                                              SEC11810
      WRITE (6,916)                                                         SEC11820
      RETURN                                                                SEC11830
    5 NSTMT=5                                                               SEC11840
      RETURN                                                                SEC11850
 7777 STOP                                                                  SEC11860
  909 FORMAT(1HO,3X,5HDPSS,1X,10E15.4)                                      SEC11870
  910 FORMAT(4A4,A2,3A4,7A4,A2,2I6)                                         SEC11880
  911 FORMAT(11I6)                                                          SEC11890
  912 FORMAT(5F12.6,/,5F12.6,/,6E12.6,/,8E12.6)                             SEC11900
  913 FORMAT(1H1,  1X,4HBEAL 7.0.                                           SEC11910
     131HPHASE TWO-COMPONENT NOZZLE FLOW ,//                                SEC11920
     2          9X,4A4,A2,//,3X,12HCASE NUMBER ,3A4,//,                     SEC11930
     38X,7A4,A2,///,10X,2HMS,10X,2HMP,9X,3HMBU,9X,3HMOB,                   SEC11940
     48X,4HMSEO,9X,3HMDS,9X,3HMSO,10X,2HTB,          9X,3HMNS,/,           SEC11950
     5 9(6X,I6),//,20X,2HDI,13X,2HBC,12X,3HPHI,11X,4HBAXO,                 SEC11960
     612X,3HSMT,          14X,1HH,11X,4HALAM,/,11X,7E15.4,                  SEC11970
     7//,10X,3HMAL,12X,3HMEL,13X,2HSA,13X,2HSB,13X,2HDO,13X,               SEC11980
     82HEO,12X,3HTGO,12X,3HTLO,/,11X,10E15.4,//,14X,3HVGO,12X,             SEC11990
     93HVL,/,11X,4ITHGO,11X,4HTHLO,12X,3HEDS,12X,3HESO,13X,2HES)           SEC12000
  914 FORMAT(6E12.8)                                                        SEC12010
  915 FORMAT(1HO,54X,16HX(P) TABLE INPUT)                                   SEC12020
  916 FORMAT(1HO,7X,23HPRINTOUT-STATION OUTPUT  )                           SEC12030
  917 FORMAT(1H ,7X,1HX,1X,10E15.4)                                         SEC12040
  918 FORMAT(1H1,120X,5HPAGE ,I3,///,55X,18HX(P) TABLE (CONT.))             SEC12050
  921 FORMAT(1HO,29HX(P) TABLE LIMITS EXCEEDED - ,                          SEC12060
     118HREAD IN NEXT CASE.)                                                SEC12070
 9913 FORMAT(1HO,10X,12E10.4//19X,3HDP1,                                    SEC12080
     1/,11X,E15.4)                                                          SEC12090
 9914 FORMAT(7A4,A2)                                                        SEC12100
 9915 FORMAT(1HO,19HX(P) TABLE FOLLOWS ,15X,11HTABLE ID - ,                 SEC12110
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     1     7A4,A2)                                                                                                  SEC12120
 8077 FORMAT(1H0,10X,19HISOTHERMAL FLOW TO ,1PE16.4 , 6H PSIA.  )                                                  SEC12130
      END                                                                                                          SEC12140
                        SUBROUTINE SECT2                                                                           SEC20010
      COMMON TZZZAY                                                                                              SEC20020
      DIMENSION TZZZAY(11200)                                                                                    SEC20030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP                                                     SEC20050
C     IT MUST BE THE FIRST COMMON BLOCK                                                                          SEC20060
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,                                    SEC20070
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,                                    SEC20080
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,                                    SEC20090
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,                                    SEC20100
     4 CBG1    , CAL     , CASE    , CBGMB   , CHG     , CBLMB   , CBL     ,                                    SEC20110
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFDM    ,                                    SEC20120
     6          CFDMS   , CGMB    , CGM     , CGMS    , CLMD    , CLM     ,                                    SEC20130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,                                    SEC20140
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,                                    SEC20150
     9          DELOS   , DELSI   , DFLSO   , DFLEM   , DELT    , DELV2   ,                                    SEC20160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DFMBG   , DFMGB   , DINT    ,                                    SEC20170
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,                                    SEC20180
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,                                    SEC20190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,                                    SEC20200
     4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTHB    ,                                    SEC20210
      COMMON    DTG     , DTHI    , DTHG    , DTL1    , DTLB    , DTL     ,                                    SEC20220
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI     ,                                    SEC20230
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMGB    ,                                    SEC20240
     8          EMGB    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,                                    SEC20250
     9          EML     , EMLS    , EMT     , EPO     , FLSSD   , FMX     ,                                    SEC20260
      COMMON    H       , HJI     , HKAG    , HKDS    , HKG11   , HKSM2   ,                                    SEC20270
     1          HKSM    , HKSMS   , HLA1    , HLAM    , HLA     , HLAS    ,                                    SEC20280
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,                                    SEC20290
     3          HOPS    , IT      , IACV    , IDLM    , IDLX    , IBM     ,                                    SEC20300
     4          IJM     , IMT     , IGLT    , IZERO   , K       , K1      ,                                    SEC20310
      COMMON    K2      , KAP     , KDACT   , KDS     , KL      , KB1     ,                                    SEC20320
     6          KR      , KTBCT   , KTB     , KXP1    , KYP     , L       ,                                    SEC20330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPBCT   ,                                    SEC20340
     8          LRM     , MBU     , MFDO    , MFP     , MGGO    , MM      ,                                    SEC20350
     9 MON     , MOP     , MTHT    , NACV    , NB      , NCLK    , NCT5    ,                                    SEC20360
      COMMON    NDIAG   , NDS     , NGS     , NTB     , NTS     , NUBT    ,                                    SEC20370
     1          NNA     , NNB     , NNDS    , NNN     , NNP     , NN      ,                                    SEC20380
     2          NNSGO   , NNSO    , NNS     , NP      , NSO     , NS      ,                                    SEC20390
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,                                    SEC20400
     4          PAS     , PBB     , PBMB    , PBOO    , PBO     , PB      ,                                    SEC20410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,                                    SEC20420
     6          PL1     , PO      , PS      , PT      , PTO     , QIO     ,                                    SEC20430
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,                                    SEC20440
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , RRF     ,                                    SEC20450
     9          REM     , RFMS    , RESLIM  , RESO    , RXSS    , RHOGB   ,                                    SEC20460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,                                    SEC20470
     1          RIM     , RI      , RM      , ROALB   , ROAL    , RUBLB   ,                                    SEC20480
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,                                    SEC20490
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,                                    SEC20500
     4          S3      , S4      , SA      , SB      , SCM     , SIL     ,                                    SEC20510
      COMMON    SITG    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,                                    SEC20520
     6          SMLB    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,                                    SEC20530
     7          SOP     , SO      , SOSM    , SS      , SZM     , SZO     ,                                    SEC20540
     8          T       , TB      , TBRAY   , TBRAY1  , TEMB    , TEO     ,                                    SEC20550
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS    ,                                    SEC20560
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TM1     ,                                    SEC20570
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,                                    SEC20580
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAO     ,                                    SEC20590
     3          VBO     , VBBS    , VBM     , VBMSQ   , VB      , VBSQ    ,                                    SEC20600
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG    ,                                    SEC20610
      COMMON    VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIBM    ,                                    SEC20620
     6          VIBMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,                                    SEC20630
     7          VL      , VLSQ    , VLS     , VS      , VSS     , WATB    ,                                    SEC20640
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBOS    ,                                    SEC20650
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,                                    SEC20660
      COMMON    WOM     , WOMS    , X       , X10     , X11     , YCLK    ,                                    SEC20670
     1          XINT    , XB      , YS      , XX      , XXA     , YI      ,                                    SEC20680
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT             ,                                    SEC20690
      DIMENSION PL(10)                                                                                           SEC20700
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      DIMENSION NDRAY(75)                                                SEC20710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                 SEC20720
     1      C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TDRAY(100),TBRAYSEC20730
     2 1(100),DRAY(75),HT(18),DINT(8)                                    SEC20740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                     SEC20750
      IF(NSTMT-30) 1,30,2                                                SEC20760
    1 CALL DUME                                                          SEC20770
    2 IF(NSTMT-145) 1,145,3                                              SEC20780
    3 IF(NSTMT-161) 1,161,4                                              SEC20790
    4 IF(NSTMT-1142) 1,1142,5                                            SEC20800
    5 CONTINUE                                                           SEC20810
C                                                                        SEC20820
C  SET ITERATION COUNT ZERO                                              SEC20830
C                                                                        SEC20840
      NNA=0                                                              SEC20850
C                                                                        SEC20860
C  SET INITIAL CONDITIONS INDICATION                                     SEC20870
C                                                                        SEC20880
C     ************** STATEMENT NO. 20  ********************************SEC20890
C     ****************************************************************SEC20900
   20 MFP=1                                                              SEC20910
      MEPO=1                                                             SEC20920
      IBLX=0                                                             SEC20930
      KAP=1                                                              SEC20940
      NNN=0                                                              SEC20950
      BO=0.0                                                             SEC20960
      PHI=PHI*0.01745329                                                 SEC20970
      AT=100000.0                                                        SEC20980
C                                                                        SEC20990
C INITIALIZE PRINTOUT COUNT                                              SEC21000
C                                                                        SEC21010
      NNP=1                                                              SEC21020
C                                                                        SEC21030
C SETUP MIDPOINT AND ENDPOINT INDICATION.                                SEC21040
C    INT = 1, NEXT ENTRY TO STATEMENT 32 COMPUTES MIDPOINT               SEC21050
C     QUANTITIES.                                                        SEC21060
C    INT = 2, NEXT ENTRY TO STATEMENT 32 COMPUTES ENDPOINT               SEC21070
C     QUANTITIES.                                                        SEC21080
C                                                                        SEC21090
      INT=1                                                              SEC21100
C                                                                        SEC21110
C   RESET THROAT INDICATOR                                               SEC21120
C     MTHT = 0 - THROAT NOT REACHED                                      SEC21130
C     MTHT = 1 - THROAT REACHED                                          SEC21140
C                                                                        SEC21150
      MTHT=0                                                             SEC21160
C                                                                        SEC21170
C  RESET DS ITERATION COUNTER.                                           SEC21180
C                                                                        SEC21190
      NNDS=0                                                             SEC21200
C  RESET OPTIMUM S ITERATION COUNTER.                                    SEC21210
C                                                                        SEC21220
C                                                                        SEC21230
      NNSO=0                                                             SEC21240
C                                                                        SEC21250
C  BACKSTEP P FOR FIRST ENTRY TO 30                                      SEC21260
C                                                                        SEC21270
      P= PO-DP1/2.0                                                      SEC21280
C                                                                        SEC21290
C  SETUP INITIAL CONDITIONS                                              SEC21300
C                                                                        SEC21310
      TG=TGO                                                             SEC21320
      TL=TLO                                                             SEC21330
      VG=VGO                                                             SEC21340
      VL=VLO                                                             SEC21350
      D=DO                                                               SEC21360
   28 X=0.                                                               SEC21370
   27 DTL=0.0                                                            SEC21380
      DS1=0.                                                             SEC21390
      R=0.                                                               SEC21400
      DTG=0.0                                                            SEC21410
      AT=0.                                                              SEC21420
                                                                         SEC21430
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      VGSQ=VG*VG                                                        SEC21440
      VLSQ=VL*VL                                                        SEC21450
      THO=THOO                                                          SEC21460
      THI=THIO                                                          SEC21470
      DELT=TG-TL                                                        SEC21480
      DELV2=VGSQ-VLSQ                                                   SEC21490
      DS1=0.                                                            SEC21500
      R=0.                                                              SEC21510
      DTHO=0.0                                                          SEC21520
      DTHI=0.0                                                          SEC21530
C     ********** STATEMENT NO. 30  **********                          SEC21540
C     ************************************************************    SEC21550
   30 NSTMT=9999                                                        SEC21560
      IF(MPP) 631,630,630                                               SEC21570
C                                                                       SEC21580
C  THIS IS FIRST POINT - HALF STEP P BY INITIAL DP STEP-SIZE.           SEC21590
C                                                                       SEC21600
  631 P=P+DP1/2.0                                                       SEC21610
      GO TO 632                                                         SEC21620
C                                                                       SEC21630
C  THIS IS NOT FIRST POINT - HALF STEP PRESSURE BY STEP                 SEC21640
C     SIZE DP.                                                          SEC21650
C                                                                       SEC21660
  630 P=P+DP/2.0                                                        SEC21670
  632 IF(P)1130,1130,131                                                SEC21680
C                                                                       SEC21690
C  STEPPING PRESSURE MADE IT NEGATIVE - PRINT DIAGNOSTIC, AND           SEC21700
C    DATA COMPUTED TO THIS POINT AND GO TO NEXT CASE.                   SEC21710
C                                                                       SEC21720
 1130 WRITE (6,930)                                                     SEC21730
      LL=1                                                              SEC21740
      GO TO 500                                                         SEC21750
C                                                                       SEC21760
C  EXTRAPOLATE TG AND TL, PRINT DIAGNOSTICS IF THEY GO                  SEC21770
C    NEGATIVE, AND PRINT DATA COMPUTED TO THIS POINT.                   SEC21780
C                                                                       SEC21790
  131 CONTINUE                                                          SEC21800
      TG=TG+DTG/2.0                                                     SEC21810
      IF(TG) 132,132,133                                                SEC21820
  132 WRITE (6,931)                                                     SEC21830
      LL=2                                                              SEC21840
      GO TO 500                                                         SEC21850
  133 TL=TL+DTL/2.0                                                     SEC21860
      IF(TL) 134,134,135                                                SEC21870
  134 WRITE (6,932)                                                     SEC21880
      LL=3                                                              SEC21890
      GO TO 500                                                         SEC21900
C                                                                       SEC21910
C  INTERPOLATE FOR PBO FOR THIS TL                                      SEC21920
C                                                                       SEC21930
  135 N=9                                                               SEC21940
      NN=9                                                              SEC21950
      CALL INTEP(PBO,N,TL,P)                                            SEC21960
      IF(N) 136,135,137                                                 SEC21970
  136 WRITE (6,9136) HT(NN),TL,P                                        SEC21980
      LL=3                                                              SEC21990
      GO TO 500                                                         SEC22000
C                                                                       SEC22010
C  CHECK DENOMINATOR OF EQUATION FOR PARTIAL PRESSURE                   SEC22020
C    OF COMPONENT A, PRINT DIAGNOSTIC IF SUFFICIENTLY                   SEC22030
C    CLOSE TO ZERO RENDERING PA INFINITE.                               SEC22040
C                                                                       SEC22050
  137 IF(ABS(1.0-H*PBO)-.0001) 138,138,139                              SEC22060
  138 WRITE (6,938)                                                     SEC22070
      LL=3                                                              SEC22080
      GO TO 500                                                         SEC22090
  139 PA=(P-PBO)/(1.0-H*PBO)                                            SEC22100
C                                                                       SEC22110
C  COMPUTE PA AND PB. IF EITHER IS NEGATIVE, PRINT                      SEC22120
C    DIAGNOSTIC AND GO TO NEXT CASE.                                    SEC22130
C
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      IF(PA) 439,440,440                                                SEC22140
  439 WRITE (6,9439)                                                    SEC22150
      LL=4                                                              SEC22160
      GO TO 500                                                         SEC22170
  440 PB=P-PA                                                           SEC22180
      IF(PB) 441,442,442                                                SEC22190
  441 WRITE (6,9440)                                                    SEC22200
      LL=5                                                              SEC22210
      GO TO 500                                                         SEC22220
C                                                                       SEC22230
C  INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT A                     SEC22240
C    GAS TABLE AT TEMPERATURE TG.                                       SEC22250
C                                                                       SEC22260
  442 N=3                                                               SEC22270
      NN=3                                                              SEC22280
      CALL INTBP(WAG,N,TG,PA)                                           SEC22290
      IF(N) 1141,1141,143                                               SEC22300
 1141 LL=5                                                              SEC22310
 1142 WRITE (6,9136) HT(NN),TG,PA                                       SEC22320
      NSTMT=9999                                                        SEC22330
      GO TO 500                                                         SEC22340
C                                                                       SEC22350
C  INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT B                     SEC22360
C    GAS TABLE AT TEMPERATURE TG.                                       SEC22370
C                                                                       SEC22380
  143 N=4                                                               SEC22390
      NN=4                                                              SEC22400
      CALL INTBP(WBG,N,TG,PB)                                           SEC22410
      IF(N) 144,144,150                                                 SEC22420
  144 LL=6                                                              SEC22430
  145 WRITE (6,9136) HT(NN),TG,PB                                       SEC22440
      NSTMT=9999                                                        SEC22450
      GO TO 500                                                         SEC22460
C                                                                       SEC22470
C  COMPUTE MEAN MOLECULAR WEIGHT OF GAS MIXTURE.                        SEC22480
C                                                                       SEC22490
  150 WG=(WAG*PA+WBG*PB)/P                                              SEC22500
C                                                                       SEC22510
C  COMPUTE RATIO OF FLOW RATE OF LIQUID A TO FLOW                       SEC22520
C    RATE OF LIQUID MIXTURE OF A AND B - ALPHA                          SEC22530
C                                                                       SEC22540
      ALPHA=((WAL/WBL)*H*PA)/(1.0+((WAL/WBL)-1.0)*H*PA)                 SEC22550
C                                                                       SEC22560
C  COMPUTE RATIO OF FLOW RATE OF GAS B TO FLOW RATE                     SEC22570
C    OF GAS MIXTURE OF A AND B - BETA                                   SEC22580
C                                                                       SEC22590
      BETA=(WBG*PB)/(WG*P)                                              SEC22600
C                                                                       SEC22610
C  COMPUTE RATIO OF FLOW RATE OF LIQUID MIXTURE TO                      SEC22620
C    FLOW RATE OF GAS MIXTURE, R. CHECK DENOMINATOR OF                  SEC22630
C    EQUATION FOR R AND PRINT DIAGNOSTIC IF SUFFICIENTLY                SEC22640
C    CLOSE TO ZERO.                                                     SEC22650
C                                                                       SEC22660
      IF(ABS(1.0-(1.0+RC)*ALPHA)-.0001) 151,152,152                     SEC22670
  151 WRITE (6,9151)                                                    SEC22680
      LL=7                                                              SEC22690
      GO TO 500                                                         SEC22700
  152 DR=((RC-(1.+RC)*BETA)/(1.0-(1.0+RC)*ALPHA))-R                     SEC22710
      R=R+DR                                                            SEC22720
C                                                                       SEC22730
C  COMPUTE GAS DENSITY - RHOG                                           SEC22740
C                                                                       SEC22750
      RHOG=(WG*P)/(TG*10.732)                                           SEC22760
C                                                                       SEC22770
C  INTERPOLATE IN TABLE FOR DENSITY OF LIQUID A AT THIS                 SEC22780
C    TEMPERATURE.                                                       SEC22790
C                                                                       SEC22800
      N=10                                                              SEC22810
      NN=10                                                             SEC22820
      CALL INTBP(ROAL,N,TL,P)                                           SEC22830
      IF(N) 160,160,162                                                 SEC22840
C                                                                       SEC22850
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C                                                                       SEC22800
C  TABLE LIMITS EXCEEDED - WRITE DIAGNOSTIC.                            SEC22810
C                                                                       SEC22820
  160 LL=8                                                              SEC22830
  161 WRITE (6,9136) HT(NN),TL,P                                        SEC22840
      NSTMT=4999                                                        SEC22850
      GO TO 500                                                         SEC22860
C                                                                       SEC22870
C  INTERPOLATE IN TABLE FOR DENSITY OF LIQUID B AT THIS                 SEC22880
C    TEMPERATURE.                                                       SEC22890
  162 N=11                                                              SEC22900
      NN=11                                                             SEC22910
      CALL INTBP(ROBL,N,TL,P)                                           SEC22920
      IF(N)161,161,163                                                  SEC22930
C                                                                       SEC22940
C  COMPUTE DENSITY OF LIQUID MIXTURE                                    SEC22950
C                                                                       SEC22960
  163 RHOL=1.0/((ALPHA/ROAL)+((1.0-ALPHA)/ROBL))                        SEC22970
C                                                                       SEC22980
C  COMPUTE FLOW RATES OF LIQUID MIXTURE AND OF GAS MIXTURE.             SEC22990
C                                                                       SEC23000
      WMG=WMT/(1.0+R)                                                   SEC23010
      WML=R*WMG                                                         SEC23020
C                                                                       SEC23030
C  COMPUTE RATIO OF GAS VOLUME FLOW TO LIQUID VOLUME FLOW.              SEC23040
C                                                                       SEC23050
      RV=RHOL/(R*RHOG)                                                  SEC23060
C                                                                       SEC23070
C  INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT                   SEC23080
C    THIS TEMPERATURE AND PRESSURE.                                     SEC23090
C                                                                       SEC23100
      N=1                                                               SEC23110
      NN=1                                                              SEC23120
      CALL INTBP(CAG,N,TG,PA)                                           SEC23130
      IF(N)165,165,170                                                  SEC23140
  165 LL=9                                                              SEC23150
      GO TO 1142                                                        SEC23160
  170 N=2                                                               SEC23170
      NN=2                                                              SEC23180
      CALL INTBP(CBG,N,TG,PB)                                           SEC23190
      LL=9                                                              SEC23200
      IF(N)145,145,171                                                  SEC23210
C  INTERPOLATE INTO LATENT HEAT OF VAPORIZATION TABLES                  SEC23220
C    FOR A AND B AT THIS TEMPERATURE.                                   SEC23230
C                                                                       SEC23240
  171 N=7                                                               SEC23250
      NN=7                                                              SEC23260
      CALL INTBP(HLA,N,TL,P)                                            SEC23270
      LL=9                                                              SEC23280
      IF(N)161,161,172                                                  SEC23290
  172 N=8                                                               SEC23300
      NN=8                                                              SEC23310
      CALL INTBP(HLB,N,TL,P)                                            SEC23320
      LL=10                                                             SEC23330
      IF(N)161,161,31                                                   SEC23340
   31 IF(MEP-1)32,40,32                                                 SEC23350
   32 IF(IET-1)60,50,60                                                 SEC23360
   40 NSTMT=40                                                          SEC23370
      RETURN                                                            SEC23380
   50 NSTMT=50                                                          SEC23390
      RETURN                                                            SEC23400
   60 NSTMT=60                                                          SEC23410
      RETURN                                                            SEC23420
  500 NDIAG=1                                                           SEC23430
      CALL OUTPUT(NNN,LDGCT,MGEO)                                       SEC23440
      NSTMT=110                                                         SEC23450
      RETURN                                                            SEC23460
  930 FORMAT(1HO,7X,13HNONPOSITIVE P)                                   SEC23470
  931 FORMAT(1HO,7X,14HNONPOSITIVE TG)                                  SEC23480
  932 FORMAT(1HO,7X,14HNONPOSITIVE TL)                                  SEC23490
  938 FORMAT(1HO,7X,11HINFINITE PA)                                     SEC23500
 9136 FORMAT(1HO,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,               SEC23510
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     14HT =  ,1PE12.4,5X,4HP =  ,E12.4)                                                SEC23580
 9151 FORMAT(1HO,7X,10HINFINITE R)                                                     SEC23590
 9439 FORMAT(1HO,7X,11HNEGATIVE PA)                                                    SEC23600
 9440 FORMAT(1HO,7X,11HNEGATIVE PB)                                                    SEC23610
      END                                                                              SEC23620
                      SUBROUTINE SECT3                                                 SEC30010
      COMMON TZZZAY                                                                    SEC30020
      DIMENSION TZZZAY(11200)                                                          SEC30030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP                           SEC30050
C     IT MUST BE THE FIRST COMMON BLOCK                                                SEC30060
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,          SEC30070
     1          ALPHS   , AM      , AO      , AS      , AT      , BA      ,          SEC30080
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,          SEC30090
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,          SEC30100
     4 CBG1    , CAL     , CASR    , CBGMB   , CBG     , CBLMB   , CBL     ,          SEC30110
      COMMON    CDMS    , CDP     , CD      , CDIM    , CDIMS   , CFDM    ,          SEC30120
     6          CFDMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,          SEC30130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DAPE    ,          SEC30140
     8          DD      , DELIM   , DELT    , DELIS   , DELOM   , DELO    ,          SEC30150
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2   ,          SEC30160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DIMT    ,          SEC30170
     1          DLSIS   , DLSOS   , DO      , DO1     , DP      , DRAY    ,          SEC30180
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,          SEC30190
     3          DSMAX   , DSMIN   , DSRAY1  , DSTAY   , DSRES1  , DSRES2  ,          SEC30200
     4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB    ,          SEC30210
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,          SEC30220
     6          DT      , DTDSQ   , DVGSQ   , DVSQ    , DX      , DXT     ,          SEC30230
     7          DYD     , ED      , EDS     , EMAGB   , EMAG    , EMGB    ,          SEC30240
     8          EMGG    , EMGB    , EMG     , EMGS    , EMLB    , EML1    ,          SEC30250
     9          EML     , EMLS    , EMT     , EOO     , EPSEP   , EQX     ,          SEC30260
      COMMON    H       , HJI     , HKAG    , HKBG    , HKGM1   , HKGM2   ,          SEC30270
     1          HKIM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,          SEC30280
     2          HLB1    , HLBM    , HLF     , HIBS    , H*      , HMS     ,          SEC30290
     3          HOPE    , HT      , IACV    , IBLK    , IBLX    , IB*     ,          SEC30300
     4          IJJ     , INP     , ISET    , IZERO   , K       , K1      ,          SEC30310
      COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KR1     ,          SEC30320
     6          KR      , KTBCT   , KTB     , KX21    , KXP     , L       ,          SEC30330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPSCT   ,          SEC30340
     8          LS*     , MBU     , MFDO    , MFP     , MGFO    , M1      ,          SEC30350
     9 N       , MOP     , MTHT    , NACV    , NB      , NCLK    , NCRS    ,          SEC30360
      COMMON    NDIAG   , NDS     , NGG     , NID     , NIS     , NLST    ,          SEC30370
     1          NNA     , NNB     , NNDS    , NNH     , NNP     , NN      ,          SEC30380
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,          SEC30390
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,          SEC30400
     4          PAS     , PBJ     , PBMB    , PBOB    , PBO     , PB      ,          SEC30410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,          SEC30420
     6          PL1     , PO      , PS      , PT      , Q       , QID     ,          SEC30430
     7          R1      , RA      , RAG     , RAXO    , RAX     , RB      ,          SEC30440
     8          RC      , RDELIN  , RDELOM  , RDIAS   , RDOMS   , REF     ,          SEC30450
     9          REM     , RESMS   , RESLIM  , RESO    , RETZ    , RHOGB   ,          SEC30460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,          SEC30470
     1          RM      , RI      , RM      , ROALB   , ROAL    , ROBLB   ,          SEC30480
     2          RCBL    , ROM     , RO      , R       , RSLIM   , RS      ,          SEC30490
     3          RV3     , RV      , RVS     , S       , S1      , S2      ,          SEC30500
     4          S3      , S4      , SA      , SB      , SBN     , SET     ,          SEC30510
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLO    ,          SEC30520
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,          SEC30530
     7          SOP     , SO      , SOSM    , SS      , SZ*     , SZO     ,          SEC30540
     8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO     ,          SEC30550
     9          TG      , TGS     , THIM    , THIO    , THI     , THIG    ,          SEC30560
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKP     ,          SEC30570
     1          TLMO    , TLO     , TL      , TLS     , TST     , TWIM    ,          SEC30580
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR     ,          SEC30590
     3          VBO     , VBOS    , VBM     , VBMSQ   , VB      , VBSQ    ,          SEC30600
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG    ,          SEC30610
      COMMON    VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIBM    ,          SEC30620
     6          VIBMS   , VIIB    , VILM    , VILMS   , VLM     , VIO     ,          SEC30630
     7          VL      , VLSQ    , VLS     , VS      , VSG     , WAG     ,          SEC30640
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,          SEC30650
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,          SEC30660
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,          SEC30670
     1          XINT    , XP      , XS      , XX      , XXA     , YI      ,          SEC30680
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     2          YIS     , YO      , YOS     , ZZZ     , NSTMT                  SEC30690
      DIMENSION PL(10)                                                         SEC30700
       DIMENSION NDRAY(75)                                                     SEC30710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                       SEC30720
     1      C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY1(100SEC30730
     21(100),DRAY(75),HT(18),DINT(8)                                           SEC30740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                           SEC30750
      IF(NSTMT-40) 1,40,2                                                      SEC30760
    1 CALL DUMP                                                                SEC30770
    2 IF(NSTMT-50) 1,50,1                                                      SEC30780
C                                                                              SEC30790
C   THIS IS FIRST POINT - STORE INITIAL PROPERTIES FOR USE                     SEC30800
C     AT END OF FIRST INTERVAL.                                                SEC30810
C                                                                              SEC30820
C        ************** STATEMENT NO. 40  ********************************** SEC30830
C        ******************************************************************** SEC30840
   40 MPP=0                                                                    SEC30850
      NSTMT=9999                                                               SEC30860
      HLA1=HLA                                                                 SEC30870
      HLB1=HLB                                                                 SEC30880
      CAG1=CAG                                                                 SEC30890
      CBG1=CBG                                                                 SEC30900
C                                                                              SEC30910
C   COMPUTE INITIAL FLOW RATES OF COMPONENTS A AND B.                          SEC30920
C                                                                              SEC30930
      EMAG=(EMG*WAG*PA)/(WG*P)                                                 SEC30940
      EMBG=(EMG*WBG*PB)/(WG*P)                                                 SEC30950
      DR=0.1                                                                   SEC30960
      IF(VG) 175,175,174                                                       SEC30970
  174 IF(VL) 175,175,176                                                       SEC30980
  175 A=1000000.                                                               SEC30990
      RA=A                                                                     SEC31000
      GO TO 41                                                                 SEC31010
C                                                                              SEC31020
C   COMPUTE INITIAL AREA OF NOZZLE.                                            SEC31030
C                                                                              SEC31040
  176 A=144.*EMG*((1.0/(RHOG*VG))+(R/(RHOL*VL)))                               SEC31050
      RA=RV*VL/VG                                                              SEC31060
   41 AT=A                                                                     SEC31070
      PT=P                                                                     SEC31080
      AP(1,1)=P                                                                SEC31090
      AP(2,1)=A                                                                SEC31100
      KAP=2                                                                    SEC31110
C                                                                              SEC31120
C   COMPUTE SLIP VELOCITY, VS, MEAN FREE STREAM VELOCITY, VB, AND              SEC31130
C     SLIP FRACTION, S.                                                        SEC31140
C                                                                              SEC31150
   42 VS=VG-VL                                                                 SEC31160
      VB=(VG+R*VL)/(1.0+R)                                                     SEC31170
      VBSQ=VB*VB                                                               SEC31180
      S=VS/VB                                                                  SEC31190
      IF(*G20) 180,179,180                                                     SEC31200
C                                                                              SEC31210
C   NOZZLE IS CIRCULAR - COMPUTE DISTANCE FROM NOZZLE AXIS TO                  SEC31220
C     WALL OF NOZZLE, YI.                                                      SEC31230
C                                                                              SEC31240
  179 YO=SQRT(A/3.1416)                                                        SEC31250
      YI=0.0                                                                   SEC31260
      RI=0.0                                                                   SEC31270
      GO TO 43                                                                 SEC31280
C                                                                              SEC31290
C   NOZZLE IS ANNULAR - COMPUTE RADII AND DISTANCES TO WALL                    SEC31300
C     OF ANNULAR NOZZLE, RI,RO,YI,YO.                                          SEC31310
C                                                                              SEC31320
  180 TST=(RAXC**2)-((A*COS(PHI))/(2.0*3.1416))                                SEC31330
      IF(TST) 181,182,182                                                      SEC31340
  181 WRITE (6,9181)                                                           SEC31350
      LL=11                                                                    SEC31360
      GO TO 500                                                                SEC31370
  182 RI=SQRT(TST)                                                             SEC31380
      RO=(RAXO**2)+((A*COS(PHI))/(2.0*3.1416))                                 SEC31390
      RO=SQRT(RO)
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      YI=(RMXO-RI)/COS(PHI)                                              SEC31400
      YO=(RO-RMXO)/COS(PHI)                                              SEC31410
C                                                                        SEC31420
C WRITE LINES 1,2,3 OF OUTPUT AND GO TO 30.                              SEC31430
C                                                                        SEC31440
   43 IF(LCT1-42)644,643,643                                             SEC31450
  643 LCT1=0                                                             SEC31460
      WRITE (6,9643) LPGCT                                               SEC31470
      LPGCT=LPGCT+1                                                      SEC31480
  644 WRITE (6,1001) X,P,R,V3,A,TG,TL,VG,VL                              SEC31490
      WRITE (6,1002) VS,S,D,AV,RA,ALPHA,BETA,EMG,EML                     SEC31500
      WRITE (6,1003) RHOG,RHOL,WAG,WBG,WG,PA,PB,HLA,HLB                  SEC31510
      LCT1=LCT1+9                                                        SEC31520
      GO TO 30                                                           SEC31530
C                                                                        SEC31540
C  MIDPOINT OF INTERVAL - COMPUTE MID-POINT PARAMETERS.                  SEC31550
C    RESET MIDPOINT/ENDPOINT INDICATOR SO NEXT ENTRY TO 32               SEC31560
C    WILL BE AN ENDPOINT.                                                SEC31570
C                                                                        SEC31580
C      ************** STATEMENT NO. 50 ********************************SEC31590
C      ****************************************************************SEC31600
   50 INT=0                                                              SEC31610
      NSTAT=9999                                                         SEC31620
C                                                                        SEC31630
C  INTERPOLATE IN VISCOSITY (GAS) TABLES FOR A AND B AT                  SEC31640
C    THIS GAS TEMPERATURE.                                               SEC31650
C                                                                        SEC31660
      N=16                                                               SEC31670
      NN=16                                                              SEC31680
      CALL INTRP(VIAG,N,TG,PA)                                           SEC31690
      IF(N)205,205,206                                                   SEC31700
  205 LL=12                                                              SEC31710
      GO TO 1142                                                         SEC31720
  206 N=17                                                               SEC31730
      NN=17                                                              SEC31740
      CALL INTRP(VIBG,N,TG,PB)                                           SEC31750
      IF(N)207,207,208                                                   SEC31760
  207 LL=12                                                              SEC31770
      GO TO 145                                                          SEC31780
C                                                                        SEC31790
C  INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT                    SEC31800
C    THIS LIQUIDS TEMPERATURE.                                           SEC31810
C                                                                        SEC31820
  208 N=5                                                                SEC31830
      NN=5                                                               SEC31840
      CALL INTRP(CAL,N,TL,P)                                             SEC31850
      LL=12                                                              SEC31860
      IF(N)161,161,209                                                   SEC31870
  209 NN=6                                                               SEC31880
      N=6                                                                SEC31890
      CALL INTRP(CBL,N,TL,P)                                             SEC31900
      LL=12                                                              SEC31910
      IF(N)161,161,210                                                   SEC31920
C                                                                        SEC31930
C  COMPUTE MEAN SPECIFIC HEATS OF LIQUID, CLM, AND OF                    SEC31940
C    GAS, CGM.                                                           SEC31950
C                                                                        SEC31960
  210 CLM=ALPHA*CAL+(1.0-ALPHA)*CBL                                      SEC31970
      CGM=(1.0-BETA)*CAG+BETA*CBG                                        SEC31980
      PHIAB=((1.0+((VIAG/VIBG)**.5)*((WBG/WAG)**.25))**2)/               SEC31990
     1      (2.828*((1.0+WAG/WBG)**.5))                                 SEC32000
      PHIBA=((1.0+((VIBG/VIAG)**.5)*((WAG/WBG)**.25))**2)/               SEC32010
     1      (2.828*((1.0+WBG/WAG)**.5))                                 SEC32020
C                                                                        SEC32030
C  COMPUTE MEAN VISCOSITY OF A AND B GAS.                                SEC32040
C                                                                        SEC32050
      VIGM=(VIAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*PHIAB))+               SEC32060
     1     (VIBG/(1.0+(((1.0-BETA)/BETA)*(WBG/WAG)*PHIBA)))            SEC32070
C                                                                        SEC32080
C  INTERPOLATE IN VISCOSITY (LIQUID) TABLES FOR A AND B AT               SEC32090
C    THIS TEMPERATURE.                                                   SEC32100
C                                                                        SEC32110
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      N=14                                                              SEC32120
      NN=14                                                             SEC32130
      CALL INTERP(VIAL,N,TL,P)                                          SEC32140
      LL=13                                                             SEC32150
      IF(N) 161,161,215                                                 SEC32160
  215 N=15                                                              SEC32170
      NN=15                                                             SEC32180
      CALL INTERP(VIBL,N,TL,P)                                          SEC32190
      LL=13                                                             SEC32200
      IF(N) 161,161,216                                                 SEC32210
C                                                                       SEC32220
CC  COMPUTE MEAN THERMAL CONDUCTIVITY OF GAS MIXTURE, HKGM.             SEC32230
CC    BA AND BB ARE USE SUBSEQUENTLY IN DETERMINING HKGM.               SEC32240
C                                                                       SEC32250
  216 VILM=ALPHA*VIAL+(1.0-ALPHA)*VIBL                                  SEC32260
      T1=(SQRT(SA*SB)/TG+1.0)**0.25                                     SEC32270
      T2=1.0+SA/TG                                                      SEC32280
      T3=1.0+SB/TG                                                      SEC32290
      T4=T2/T3                                                          SEC32300
      T5=(WAG/WBG)**0.75                                                SEC32310
      T6=VIAG/VIBG                                                      SEC32320
      T7=SQRT(T6*T4*T5)                                                 SEC32330
      BA=T1/T2*(1.0+T7)**2                                              SEC32340
      BB=T1/T3*(1.0+1.0/T7)**2                                          SEC32350
C                                                                       SEC32360
CC    INTERPOLATE IN THERMAL CONDUCTIVITY TABLES FOR COMPONENTS         SEC32370
CC      A AND B IN GASEOUS STATE.                                       SEC32380
C                                                                       SEC32390
      N=12                                                              SEC32400
      NN=12                                                             SEC32410
      CALL INTERP(HKAG,N,TG,P)                                          SEC32420
      LL=13                                                             SEC32430
      IF(N) 145,145,220                                                 SEC32440
  220 N=13                                                              SEC32450
      NN=13                                                             SEC32460
      CALL INTERP(HKBG,N,TG,P)                                          SEC32470
      LL=13                                                             SEC32480
      IF(N) 145,145,221                                                 SEC32490
C                                                                       SEC32500
CC      IF BETA=1, FIRST TERM OF HKGM IS SET=0                          SEC32510
CC      IF BETA=0, SECOND TERM OF HKGM IS SET=0                         SEC32520
C                                                                       SEC32530
  221 IF(BETA-1.0) 223,222,223                                          SEC32540
  222 HKGM1=0.0                                                         SEC32550
      GO TO 224                                                         SEC32560
  223 HKGM1=HKAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*BA)                   SEC32570
  224 IF(BETA) 225,225,226                                              SEC32580
  225 HKGM2=0.0                                                         SEC32590
      GO TO 227                                                         SEC32600
  226 HKGM2=HKBG/(1.0+((1.0+BETA)/BETA)*(WBG/WAG)*BB)                   SEC32610
  227 HKGM=HKGM1+HKGM2                                                  SEC32620
C                                                                       SEC32630
CC      COMPUTE V1,V2,R1, HERE FOR USE IN ITERATIVE LOOP AT             SEC32640
CC      STATEMENT NO. 70.                                               SEC32650
C                                                                       SEC32660
      V1=((99443.6*TG)/((1.0+R)*WG))*ALOG                               SEC32670
     1       ((P+DP/2.0)/(P-DP/2.0))                                    SEC32680
      V2=(9266.08*DP)/((1.0+R)*RHOL)                                    SEC32690
      R1=(300.0*RHOG*D)/VIGM                                            SEC32700
      IF(MOP) 51,52,51                                                  SEC32710
C                                                                       SEC32720
CC    OPTIMUM X(P) IS TO BE USED.                                       SEC32730
CC                                                                      SEC32740
CC      ********** STATEMENT NO. 51  **********                        SEC32750
C       ************************************************************* SEC32760
   51 C1=(D*ALAM*RHOL)/(9.0*RHOG)                                       SEC32770
      SMLG=R/((1.0+R)**2)                                               SEC32780
16070 KDS = 1                                                           SEC32790
      KDSCT = 0                                                         SEC32800
      NNSO = 0                                                          SEC32810
      NNSOO = 0                                                         SEC32820
      DSMIN = -2.*(S+(1.+R)/R)+1.0E-06                                  SEC32830
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      DSMAX = 1.0 + R - 1.0E-06                                          SEC32350
      GO TO 70                                                           SEC32360
C                                                                        SEC32370
C   SPECIFIED X(P) IS TO BE USED.                                        SEC32380
C                                                                        SEC32390
   52 P10=P+DP/2.0                                                       SEC32900
      P11=P-DP/2.0                                                       SEC32910
      PINT=P10                                                           SEC32920
      KL=1                                                               SEC32930
      GO TO 1100                                                         SEC32940
 1152 X10=XINT                                                           SEC32950
      PINT=P11                                                           SEC32960
      KL=2                                                               SEC32970
      GO TO 1100                                                         SEC32980
 1153 X11=XINT                                                           SEC32990
C                                                                        SEC33000
C   GET DIFFERENCE OF INTERPOLATED X VALUES FROM                         SEC33010
C    X(P) TABLE                                                          SEC33020
C                                                                        SEC33030
      DX=X10-X11                                                         SEC33040
      S1=(0.75*RHOG*(1.0+R)*DX)/(D*RHOL)                                 SEC33050
      S2=(4633.04*(1.0+R)*DP)/RHOL                                       SEC33060
      S3=(1.0+R)/2.0                                                     SEC33070
      S4=2.0*DP/(1.0+R)                                                  SEC33080
      GO TO 16070                                                        SEC33090
C                                                                        SEC33100
C   INTERPOLATE INTO X(P) TABLE FOR TWO PRESSURE VALUES                  SEC33110
C    AT EITHER SIDE OF CURRENT INTERVAL.                                 SEC33120
C                                                                        SEC33130
 1100 CONTINUE                                                           SEC33140
C     THIS CHANGE TO ALLOW FOR MONOTONIC INCREASING OR DECREASING TABLES SEC33150
      TERZ=PINT-XP(1,1)*1.0E-6                                           SEC33160
      IF(TERZ*(XP(1,1)-XP(1,2)))1106,1102,1105                           SEC33170
 1106 CONTINUE                                                           SEC33180
      DO 1103 KR=2,KXP1                                                  SEC33190
      TERY=XP(1,KR)-PINT                                                 SEC33200
      IF(TERY*TERZ)1101,1104,1104                                        SEC33210
 1101 TERZ=-TERY                                                         SEC33220
 1103 CONTINUE                                                           SEC33230
      GO TO 1120                                                         SEC33240
 1102 CONTINUE                                                           SEC33250
      KR=2                                                               SEC33260
 1104 KR1=KR-1                                                           SEC33270
      XINT=XP(2,KR1)+TERZ/(XP(1,KR)-XP(1,KR1))*(XP(2,KR)-XP(2,KR1))      SEC33280
      GO TO (1152,1153),KL                                               SEC33290
 1105 CONTINUE                                                           SEC33300
      IF (TERZ-0.001) 1108,1120,1120                                     SEC33301
 1108 IF (TERZ+0.001) 1120,1120,1110                                     SEC33302
 1110 TERZ=-1.00*TERZ                                                    SEC33303
      GO TO 1106                                                         SEC33304
 1120 WRITE (6,9105) P10,P11,KL,TERZ,TERY,PINT                           SEC33311
      LL=10                                                              SEC33320
      GO TO 500                                                          SEC33330
   30 NSTMT=30                                                           SEC33340
      RETURN                                                             SEC33350
 1142 NSTMT=1142                                                         SEC33360
      RETURN                                                             SEC33370
  145 NSTMT=145                                                          SEC33380
      RETURN                                                             SEC33390
  161 NSTMT=161                                                          SEC33400
      RETURN                                                             SEC33410
   70 NSTMT=70                                                           SEC33420
      RETURN                                                             SEC33430
  500 NDIAG=1                                                            SEC33440
      CALL OUTPUT(NNN,LPGCT,NGEO)                                        SEC33450
      NSTMT=110                                                          SEC33460
      RETURN                                                             SEC33470
C                                                                        SEC33480
C   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.                       SEC33490
C                                                                        SEC33500
 1001 FORMAT(1HO,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,  SEC33510
     12HTL,12X,2HVG,12X,2HVL,/,6(,1PE14.4))                              SEC33520
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 1002 FORMAT(1HO,12X,2HVS,13X,1HS,13X,1HD,12X,2HDV,12X,2HDA,9X,          SEC33530
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,1P8E14.4)                SEC33540
 1003 FORMAT(1HO,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,      SEC33550
     112X,2HPA,12X,2HEB,12X,2HLA,12X,2HLS,/,6X,1P8E14.4)                 SEC33560
 9105 FORMAT(1HO,19HSTEP 52 - PRESSURE OUT OF RANGE OF KP               SEC33570
     1      16HTABLE.     P1 = ,1PE14.4,3X,5HP2 = ,E14.4,/,7X,7HPROCESS, SEC33580
     2      24H CONTINUED TO NEXT CASE.,27H  OUTPUT OF LAST ITERATION ,  SEC33590
     3      8HFCLID=3./120,3020.7)                                       SEC33600
 9181 FORMAT(1HO,7X,11HNEGATIVE RI)                                      SEC33610
 9643 FORMAT(1H1,120X,5HPAGE ,I3,/,1HO,28H REAL TWO-PHASE TWO-COMPONENT  SEC33620
     1,12H NOZZLE FLOW// )                                               SEC33630
      END                                                                SEC33640
                      SUBROUTINE SECT4                                   SEC40010
      COMMON TZZZAY                                                      SEC40020
      DIMENSION TZZZAY(11200)                                            SEC40030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP             SEC40040
C     IT MUST BE THE FIRST COMMON BLOCK                                  SEC40050
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BA     ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM     ,
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB  ,
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL    ,
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CJOM   ,
     6          CFMS    , CGMM    , CGM     , CGMS    , CLMB    , CLS    ,
     7          CLMS    , CSAVE   , D       , D2      , DA      , DA2S   ,
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO   ,
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2  ,
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT   ,
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY   ,
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM  ,
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2 ,
     4          DSRES   , DS      , DSX1    , DSX2    , DT1     , DT1B   ,
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTL8    , DTL    ,
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI    ,
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMBGB  ,
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM   ,
     9          EML     , EMLS    , EMT     , ESQ     , PLSSP   , FBX    ,
      COMMON    H       , HJI     , HKAG    , HKEG    , HKSM1   , HASM2  ,
     1          HKSM    , HKSMS   , HLA1    , HLAM    , HLA     , HLAS   ,
     2          HLB1    , HLB4    , HLD     , HLBS    , HM      , HMS    ,
     3          HOPR    , HT      , IACV    , IBLM    , IBLX    , IBM    ,
     4          IJM     , INT     , ISET    , IZERO   , K       , K1     ,
      COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KP1    ,
     6          KP      , KTSCT   , KTS     , KXP1    , KXP     , L      ,
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPSCT  ,
     8          LSW     , MBH     , MFFO    , MFP     , MGEO    , MM     ,
     9 N      , MOP     , MTHT    , NACV    , NB      , NCLX    , NCTS   ,
      COMMON    NDIAG   , NDS     , NGG     , NIB     , NIS     , NLST   ,
     1          NMA     , NNB     , NNDS    , NNM     , NNP     , NNT    ,
     2          NNSOO   , NNSS    , NP      , NSG     , NS      , NA     ,
     3          P       , P10     , P11     , PAB     , PAMB    , PA     ,
     4          PAS     , PBO     , PBMB    , PBOB    , PBO     , PB     ,
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL     ,
     6          PL1     , PO      , PS      , PT      , Q       , QID    ,
     7          R1      , RA      , RAS     , RAYO    , RAY     , RB     ,
     8          RC      , RDELIM  , RDELOM  , RDINS   , RDOMS   , RDS    ,
     9          REM     , RFMS    , RESSIM  , RESO    , RESZ    , RHOGB
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS  ,
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROOLB  ,
     2          ROOL    , ROM     , RO      , R       , RSLIM   , RS     ,
     3          RVB     , RV      , RVS     , S       , S1      , S2     ,
     4          SB      , SG      , SA      , SB      , SGN     , SIG    ,
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLO   ,
     6          SMLS    , SMLP    , SMLG    , SM      , SOJ1    , SOJ2   ,
     7          SOP     , SO      , SOSM    , SS      , SZM     , SZO    ,
     8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TMO    ,
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TK1    ,
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM   ,
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR    ,
     3          VBO     , VBOS    , VBM     , VBMSQ   , VB      , VBSQ   ,
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG   SEC40610
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      COMMON    VIALB  , VIAL   , VISG   , VISLB  , VISL   , VISN   ,     SEC40620
     6          VISMS  , VILB   , VILN   , VILMS  , VLM    , VLO    ,     SEC40630
     7          VL     , VLSQ   , VLS    , VS     , VSS    , WAGB   ,     SEC40640
     8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,     SEC40650
     9          WEL    , WGB    , WG     , WGS    , WIM    , WIMS   ,     SEC40660
      COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLK   ,     SEC40670
     1          XINT   , XP     , XS     , XX     , XXA    , YI     ,     SEC40680
     2          YIS    , YO     , YOS    , ZZZ    , NSTMT                 SEC40690
      DIMENSION PL(10)                                                    SEC40700
      DIMENSION NDRAY(75)                                                 SEC40710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                  SEC40720
     1     C(6),AS(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAYSEC40730
     2 1(100),DRAY(75),HT(18),DINT(8)                                     SEC40740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                      SEC40750
      IF(NSTMT-60) 1,60,2                                                 SEC40760
    1 CALL DUMP                                                           SEC40770
    2 IF(NSTMT-63) 1,63,1                                                 SEC40780
C                                                                         SEC40790
C    END POINT OF THIS INTERVAL OF PRESSURE.                              SEC40800
C      COMPUTE CHANGES IN FLOW PARAMETERS THIS INTERVAL.                  SEC40810
C                                                                         SEC40820
C      ********** STATEMENT NO. 60  **********                           SEC40830
C      ************************************************************       SEC40840
   60 INT=1                                                               SEC40850
      NSTMT=9999                                                          SEC40860
      VB=ABS(SQRT(VBSQ))                                                  SEC40870
C                                                                         SEC40880
C    COMPUTE NEW SLIP FRACTION, S, AND NEW DISTANCE, X.                   SEC40890
C                                                                         SEC40900
      IF(MPPO-1)4001,4000,4001                                            SEC40910
 4000 S=SM                                                                SEC40920
      GO TO 4002                                                          SEC40930
 4001 S=S+DS                                                              SEC40940
 4002 X=X+DX                                                              SEC40950
C                                                                         SEC40960
C    COMPUTE CHANGES IN SQUARE OF GAS AND LIQUID VELOCITIES.              SEC40970
C                                                                         SEC40980
      DVGSQ=((1.0+(R*S)/(1.0+R))**2)*VBSQ-VGSQ                            SEC40990
      DVLSQ=((1.0-S/(1.0+R))**2)*VBSQ-VLSQ                                SEC41000
C                                                                         SEC41010
C    COMPUTE CHANGES IN GAS AND LIQUID FLOW RATES.                        SEC41020
C                                                                         SEC41030
      DEMAG=(EMG*WAG*PA)/(WG*P)-EMAG                                      SEC41040
      DEMBG=(EMG*WBG*PB)/(WG*P)-EMBG                                      SEC41050
C                                                                         SEC41060
C    COMPUTE CHANGES IN GAS AND LIQUID TEMPERATURES.                      SEC41070
C                                                                         SEC41080
      DTL=(1.0/CLM)*(((HM*DELTM*DX)/(600.0*D*RHOLM*VLM))                  SEC41090
     1     -(HLAM*DEMAG/EMLM)-(HLBM*DEMB)/EMLM))                        SEC41100
      DELT=TG-TL                                                          SEC41110
      DTG=(-1.0/CGM)*((DVGSQ/50072.9)+R*                                  SEC41120
     1     (CLM*DTL+DP/(5.4039*RHOLM)+DVLSQ/50072.9)+                     SEC41130
     2     ((DEMAG+DEMBG)*DELV2)/(50072.9*EMG)+                           SEC41140
     3     ((HLA1+CAG1*DELT)*DEMAG+(HLB1+CBG1*DELT)*                      SEC41150
     4DEMBG)/EMG)                                                         SEC41160
      IF(( 1.0 + (R * CLM / CGM)) * ((HM * DX) / (600.0 * D * CLM * RHOLSEC41170
     1M * VLM)) - 1.) 8075,8076,8076                                      SEC41180
 8076 DTL = 0.                                                            SEC41190
      DTG = 0.0                                                           SEC41200
      IF(P-0.5*PO)8075,8074,8074                                          SEC41210
 8074 CONTINUE                                                            SEC41220
C     THIS LAST TEST ADDED TO DELETE NEXT TEST AT END OF NOZZLE           SEC41230
      XX=P                                                                SEC41240
C     CHANGE TO SAVE THE LAST P FOR PRINTOUT IN SECT1.                    SEC41250
 8075 CONTINUE                                                            SEC41260
C    COMPUTE NEW TEMPERATURES FOR LIQUID AND GAS.                         SEC41270
C     IF EITHER IS NEGATIVE PRINT DIAGNOSTIC AND EXIT                     SEC41280
C     TO NEXT CASE.                                                       SEC41290
      VGSQ=VGSQ+DVGSQ                                                     SEC41300
      IF(VGSQ)230,230,231                                                 SEC41310
  230 WRITE (6,9230)                                                      SEC41320
      LL=15                                                               SEC41330
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      GO TO 500                                                         SEC4 1340
  231 VLSQ=VLSQ+DVLSQ                                                   SEC4 1350
      IF(VLSQ)232,232,233                                               SEC4 1360
  232 WRITE (6,9232)                                                    SEC4 1370
      LL=15                                                             SEC4 1380
      GO TO 500                                                         SEC4 1390
C                                                                       SEC4 1400
C   COMPUTE NEW VELOCITIES FOR LIQUID AND GAS.                          SEC4 1410
C                                                                       SEC4 1420
C                                                                       SEC4 1430
  233 VG=ABS(SQRT(VGSQ))                                                SEC4 1440
      VL=ABS(SQRT(VLSQ))                                                SEC4 1450
C                                                                       SEC4 1460
C   COMPUTE RATIO OF GAS FLOW AREA TO LIQUID FLOW AREA.                 SEC4 1470
C                                                                       SEC4 1480
      RA=RV*(VL/VG)                                                     SEC4 1490
C                                                                       SEC4 1500
C   COMPUTE NEW LIQUID AND GAS FLOW RATES.                              SEC4 1510
C                                                                       SEC4 1520
      EMAG=EMAG+DEMAG                                                   SEC4 1530
      EMBG=EMBG+DEMBG                                                   SEC4 1540
      DELV2=VGSQ-VLSQ                                                   SEC4 1550
C                                                                       SEC4 1560
C   SET UP INITIAL QUANTITIES FOR NEXT END-POINT.                       SEC4 1570
C                                                                       SEC4 1580
      DTL1=DTL                                                          SEC4 1590
      DTG1=DTG                                                          SEC4 1600
      HLA1=HLA                                                          SEC4 1610
      HLB1=HLB                                                          SEC4 1620
      DELT=TG-TL                                                        SEC4 1630
      CAG1=CAG                                                          SEC4 1640
      CBG1=CBG                                                          SEC4 1650
      VS=S*VB                                                           SEC4 1660
C                                                                       SEC4 1670
C   INTERPOLATE INTO SURFACE TENSION TABLE AT THIS LIQUID               SEC4 1680
C    TEMPERATURE.                                                       SEC4 1690
C                                                                       SEC4 1700
      N=18                                                              SEC4 1710
      NN=19                                                             SEC4 1720
      CALL INTRP(SIG,N,TL,2)                                            SEC4 1730
      LL=16                                                             SEC4 1740
      IF(N)161,161,240                                                  SEC4 1750
C   IF DROPLET BREAKUP OPTION SPECIFIED, COMPUTE DROPLET                SEC4 1760
C    DIAMETER.                                                          SEC4 1770
  240 IF(MFU-1)243,238,243                                              SEC4 1780
  238 D2=(.3174*SIG)/(RHOG*VS**2)                                       SEC4 1790
      IF(D-D2)243,243,239                                               SEC4 1800
  239 D=D2                                                              SEC4 1810
C                                                                       SEC4 1820
C   COMPUTE CHANGE IN NOZZLE CROSS-SECTIONAL AREA SINCE                 SEC4 1830
C    LAST END-POINT.                                                    SEC4 1840
C                                                                       SEC4 1850
  243 DA=144.0*EMG*(1.0/(RHOG*VG)+R/(RHOL*VL))-A                        SEC4 1860
C                                                                       SEC4 1870
C   COMPUTE MEAN AREA BETWEEN THIS AND  REVIOUS ENDPOINT.               SEC4 1880
C                                                                       SEC4 1890
      AM=A+DA/2.0                                                       SEC4 1900
C                                                                       SEC4 1910
C   COMPUTE PRESENT AREA                                                SEC4 1920
C                                                                       SEC4 1930
      A=A+DA                                                            SEC4 1940
      IF(MGEO-1)67,68,67                                                SEC4 1950
C                                                                       SEC4 1960
C   COMPUTE RADII AND DISTANCE FROM AXIS TO WALL OF                     SEC4 1970
C    CIRCULAR NOZZLE.                                                   SEC4 1980
C      ********** STATEMENT NO. 67  **********                         SEC4 1990
C      ************************************************************   SEC4 2000
   67 DYO=SQRT(A/3.1416)-YO                                             SEC4 2010
      RCM=YO+DYO/2.0                                                    SEC4 2020
      DRO=DYO                                                           SEC4 2030
      YO=YO+DYO                                                         SEC4 2040
      RO=YO                                                             SEC4 2050
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      WIM=0.0                                                           SEC4 2060
      DELI =0.0                                                         SEC4 2070
      DELSI=0.0                                                         SEC4 2080
      RDELIM=0.0                                                        SEC4 2090
      CFIM=0.0                                                          SEC4 2100
      TWIM =0.0                                                         SEC4 2110
      GO TO 64                                                          SEC4 2120
C                                                                       SEC4 2130
C     COMPUTE GEOMETRY OF ANNULAR NOZZLE AND BOUNDARY-LAYER             SEC4 2140
C      GROWTH AND SWEAR FOR INNER WALL.                                 SEC4 2150
C                                                                       SEC4 2160
   68 RAX=RAXO-X*SIN(PHI)                                               SEC4 2170
      IF(RAX**2-(A*COS(PHI))/(2.0*3.1416))241,242,242                   SEC4 2180
  241 WRITE (6,9241)                                                    SEC4 2190
      LL=17                                                             SEC4 2200
      GO TO 500                                                         SEC4 2210
  242 DRI=SQRT(RAX**2-(A*COS(PHI))/(2.0*3.1416))-RI                     SEC4 2220
      DRC=SQRT(RAX**2+(A*COS(PHI))/(2.0*3.1416))-RO                     SEC4 2230
      RIM=RI+DRI/2.0                                                    SEC4 2240
      RI=RI+DRI                                                         SEC4 2250
      ROM=RO+DRO/2.0                                                    SEC4 2260
      RO=RO+DRC                                                         SEC4 2270
      DYI=(RAX-RI)/(COS(PHI))-YI                                        SEC4 2280
      DYO=(RO-RAX)/(COS(PHI))-YO                                        SEC4 2290
      YI=YI+DYI                                                         SEC4 2300
      YO=YO+DYC                                                         SEC4 2310
C                                                                       SEC4 2320
C     COMPUTE ANGLE OF NOZZLE INNER WALL RELATIVE TO AXIS.              SEC4 2330
C                                                                       SEC4 2340
      WIM=(ATAN(DYI/DX))                                                SEC4 2350
      WI=WIM*57.29578                                                   SEC4 2360
  246 DTHI=0.5*CFIM*((RM*BM)/(1.0+RM))*DX-  THIM*                       SEC4 2370
     1      ((1.141*DVBSQ)/VBMSQ-DA/AM+DRI/RIM)                        SEC4 2380
      TWIM=(CFIM*RHOL*VLSQ)/(6559.6*(1.0+RA))                           SEC4 2390
      THI=THI+DTHI                                                      SEC4 2400
      DELI=10.286*THI                                                   SEC4 2410
      DELSI=1.2857*THI                                                  SEC4 2420
   69 DTHO=0.5*CFOM*((RM*BM)/(1.0+RM))*DX-THOM*                         SEC4 2430
     1      ((1.141*DVBSQ)/VBMSQ-DA/AM+DRO/ROM)                        SEC4 2440
      TWOM=(CFOM*RHOL*VLSQ)/(6559.6*(1.0+RA))                           SEC4 2450
      THO=THO+DTHO                                                      SEC4 2460
      DELO=10.286*THO                                                   SEC4 2470
      DELSO=1.2857*THO                                                  SEC4 2480
C                                                                       SEC4 2490
C     COMPUTE ANGLE OF NOZZLE OUTER WALL RELATIVE TO AXIS.              SEC4 2500
C                                                                       SEC4 2510
      WOM=ATAN(DYO/DX)                                                  SEC4 2520
      WOM=57.29578*WOM                                                  SEC4 2530
C                                                                       SEC4 2540
C     COMPUTE MEAN VELOCITY (INCLUDING BOUNDARY LAYER).                 SEC4 2550
C                                                                       SEC4 2560
  251 VBD=VB*(1.0-((2.0*3.1416)/A)*                                     SEC4 2570
     1      (RO*THO+RI*THI))                                           SEC4 2580
      GO TO 61                                                          SEC4 2590
C                                                                       SEC4 2600
C     IF AREA LESS ZERO, NOZZLE IS CONVERGING AND THROAT HAS            SEC4 2610
C      NOT JUST BEEN PASSED. IF NOT, NOZZLE THROAT MAY                  SEC4 2620
C      HAVE JUST BEEN PASSED.                                           SEC4 2630
C                                                                       SEC4 2640
   61 IF(A-AT)66,62,62                                                  SEC4 2650
C                                                                       SEC4 2660
C     ADVANCE STEP COUNT AND RETURN TO STEP 30 IF MAXIMUM               SEC4 2670
C       STEP COUNT NOT REACHED.                                         SEC4 2680
C                                                                       SEC4 2690
   62 NNS=NNS+1                                                         SEC4 2700
      IF(NNS-NS)30,260,260                                              SEC4 2710
C                                                                       SEC4 2720
C     INITIALIZE TB AND COUNTERS AND GO TO STEP 140 TO                  SEC4 2730
C       COMPUTE EARRED QUANTITIES.                                      SEC4 2740
C                                                                       SEC4 2750
  260 TB=TL                                                             SEC4 2760
      NNS=0                                                             SEC4 2770
```

```
      NNB=1                                                             SBC4 2720
      GO TO 140                                                         SBC4 2730
C                                                                       SBC4 2740
C     OUTPUT HAS JUST BEEN PRINTED.  RETURN TO STEP 30                  SBC4 2750
C       IF ITERATION IS NOT COMPLETED.                                  SBC4 2760
C                                                                       SBC4 2770
   63 NNP=NNP+1                                                         SBC4 2780
      NSTMT=9999                                                        SBC4 2790
      IF(NNP-NF)30,64,64                                                SBC4 2800
C                                                                       SBC4 2810
C                                                                       SBC4 2820
   64 PL1(1)=XS                                                         SBC4 2830
      PL1(2)=PS                                                         SBC4 2840
      PL1(3)=RS                                                         SBC4 2850
      PL1(4)=VBS                                                        SBC4 2860
      PL1(5)=AS                                                         SBC4 2870
      PL1(6)=TGS                                                        SBC4 2880
      PL1(7)=TLS                                                        SBC4 2890
      PL1(8)=VGS                                                        SBC4 2900
      PL1(9)=VLS                                                        SBC4 2910
      PL1(10)=1.0                                                       SBC4 2920
C     WRITE (18) PL1                                                    SBC4 2930
      MM=MM+1                                                           SBC4 2940
  264 CALL OUTPUT (NNN,LPGCT,MGRO)                                      SBC4 2950
      GO TO 110                                                         SBC4 2960
   66 AI=A                                                              SBC4 2970
      PI=P                                                              SBC4 2980
      XS=X                                                              SBC4 2990
      PS=P                                                              SBC4 3000
      TLS=TL                                                            SBC4 3010
      VGS=VG                                                            SBC4 3020
      RS=R                                                              SBC4 3030
      VBS=VB                                                            SBC4 3040
      AS=A                                                              SBC4 3050
      TGS=TG                                                            SBC4 3060
      VLS=VL                                                            SBC4 3070
      VSS=VS                                                            SBC4 3080
      SS=S                                                              SBC4 3090
      DD=D                                                              SBC4 3100
      RVS=RV                                                            SBC4 3110
      RAS=RA                                                            SBC4 3120
      ALPHS=ALPHA                                                       SBC4 3130
      BETAS=BETA                                                        SBC4 3140
      EMGS=EMG                                                          SBC4 3150
      EMLS=EML                                                          SBC4 3160
      RHCGS=RHCG                                                        SBC4 3170
      RHCLS=RHCL                                                        SBC4 3180
      WAGS=WAG                                                          SBC4 3190
      WBGS=WBG                                                          SBC4 3200
      WGS=WG                                                            SBC4 3210
      DAS=DA                                                            SBC4 3220
      PBS=PB                                                            SBC4 3230
      HLAS=HLA                                                          SBC4 3240
      HLBS=HLB                                                          SBC4 3250
      SIGS=SIG                                                          SBC4 3260
      CGMS=CGM                                                          SBC4 3270
      CLMS=CLM                                                          SBC4 3280
      VIGMS=VIGM                                                        SBC4 3290
      VILMS=VILM                                                        SBC4 3300
      HKGMS=HKGM                                                        SBC4 3310
      REMS=REM                                                          SBC4 3320
      CDMS=CD                                                           SBC4 3330
      HMS=HM                                                            SBC4 3340
      YOS=YO                                                            SBC4 3350
      WOMS=WOM                                                          SBC4 3360
      THOS=THO                                                          SBC4 3370
      DELOS=DELO                                                        SBC4 3380
      DLSOS=DELSO                                                       SBC4 3390
      RDOMS=RDELOM                                                      SBC4 3400
      CFCMS=CFCM                                                        SBC4 3410
      TWOMS=TWCM                                                        SBC4 3420
      VBDS=VBD                                                          SBC4 3430
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      XIS=XI                                                                 SBC4 3440
      WIMS=WIM                                                               SBC4 3450
      THIS=THI                                                               SBC4 3460
      DELIS=DELI                                                             SBC4 3470
      DLSIS=DELSI                                                            SBC4 3480
      RDIMS=RDELIM                                                           SBC4 3490
      CFIMS=CFIM                                                             SBC4 3500
      TWIDS=TWIM                                                             SBC4 3510
      GO TO 62                                                               SBC4 3520
   30 NSIMT=30                                                               SBC4 3530
      RETURN                                                                 SBC4 3540
  140 NSIMT=140                                                              SBC4 3550
      RETURN                                                                 SBC4 3560
  161 NSIMT=161                                                              SBC4 3570
      RETURN                                                                 SBC4 3580
  500 MDIAG=1                                                                SBC4 3590
      CALL OUTPUT(NNN,LPGCT,MG20)                                            SBC4 3600
  110 NSIMT=110                                                              SBC4 3610
      RETURN                                                                 SBC4 3620
 9230 FORMAT(1H0,7X,14HNONPOSITIVE VG)                                       SBC4 3630
 9232 FORMAT(1H0,7X,14HNONPOSITIVE VL)                                       SBC4 3640
 9241 FORMAT(1H0,7X,11HNEGATIVE RI)                                          SBC4 3650
      END                                                                    SBC4 3660
                    SUBROUTINE SECT5                                         SBC50010
      COMMON TZZZAY                                                          SBC50020
      DIMENSION TZZZAY(11200)                                                SBC50030
C     THE ABOVE COMMON BLOCK POS SUBROUTINES TABLE AND INTRP                 SBC50050
C     IT MUST BE THE FIRST COMMON BLOCK                                      SBC50060
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,SBC50070
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,SBC50080
     2          BB      , BBTAB   , BETAMB  , BETA    , BETAS   , BM      ,SBC50090
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,SBC50100
     4  CBG1    , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL     ,SBC50110
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFDM    ,SBC50120
     6          CFDMS   , CGAB    , CGM     , CGMS    , CLMS    , CLM     ,SBC50130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DAFE    ,SBC50140
     8          DB      , DELIM   , DELI    , DELIS   , DELDM   , DELD    ,SBC50150
     9          DELDS   , DELSI   , DELSQ   , DFIFM   , DELT    , DELV2   ,SBC50160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DFMDG   , DFMGB   , DIFF    ,SBC50170
     1          DLSIS   , DLSQS   , DO      , DP1     , DP      , DSAV    ,SBC50180
     2          DRI     , DRQ     , DR      , DS1     , DSAVE   , DSLIM   ,SBC50190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,SBC50200
     4          DSPES   , DS      , DSX1    , DSX2    , DTH1    , DTH2    ,SBC50210
      COMMON    DTS     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,SBC50220
     6          DT      , DVMSQ   , DVGSQ   , DVESQ   , DX      , DY1     ,SBC50230
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMGB    ,SBC50240
     8          EMDS    , EMIB    , EMS     , EMS     , EMLB    , EMLM    ,SBC50250
     9          EML     , EMLS    , EMT     , ESO     , FLSSP   , FUX     ,SBC50260
      COMMON    H       , HDI     , HKAG    , HKBG    , HKGM1   , HKGM2   ,SBC50270
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,SBC50280
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,SBC50290
     3          HOPE    , HT      , IACV    , IFLW    , IBLX    , IBM     ,SBC50300
     4          IJH     , INT     , ISET    , IZERO   , K       , K1      ,SBC50310
      COMMON    K2      , KAP     , KBSCT   , KDS     , KL      , KM1     ,SBC50320
     6          KR      , KTRCT   , KTB     , KXP1    , KXP     , L       ,SBC50330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT   ,SBC50340
     8          LSW     , MDU     , MFEO    , MFP     , MG20    , MM      ,SBC50350
     9  N       , NOP     , NEAT    , NACV    , NE      , NCLK    , NCP5    ,SBC50360
      COMMON    NDIAG   , NDS     , NGB     , NIB     , NIS     , NLST    ,SBC50370
     1          NNA     , NNB     , NNDS    , NNM     , NNP     , NN      ,SBC50380
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,SBC50390
     3          P       , P10     , P11     , PA9     , PAMB    , PA      ,SBC50400
     4          PAS     , PBO     , PBMB    , PBOB    , PBO     , PB      ,SBC50410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,SBC50420
     6          PL1     , PO      , PS      , QT      , Q       , QTO     ,SBC50430
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,SBC50440
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , RE      ,SBC50450
     9          REM     , RENS    , RESLIM  , RESO    , RESS    , RHOGB   ,SBC50460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,SBC50470
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROOLB   ,SBC50480
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,SBC50490
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,SBC50500
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     4              S3      , S4      , SA      , SB      , SGN     , SIG           SEC50510
      COMMON        SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,   SEC50520
     6              SMLE    , SMLP    , SMLG    , SM      , SOJ1    , SOJ2    ,   SEC50530
     7              SOP     , SO      , SOSM    , SS      , SSM     , SZO     ,   SEC50540
     8              T       , TB      , TBRAY   , TBRAY1  , TGM3    , TGO     ,   SEC50550
     9              TG      , TGS     , THIM    , THIO    , THI     , THIS          SEC50560
      COMMON        THOM    , THOO    , THO     , TMOS    , TK      , TKP     ,   SEC50570
     1              TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,   SEC50580
     2              TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR     ,   SEC50590
     3              VBO     , VBOS    , VBM     , VBMSQ   , VB      , VBSQ    ,   SEC50600
     4              VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG          SEC50610
      COMMON        VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,   SEC50620
     6              VIGMS   , VILB    , VILM    , VILMS   , VLV     , VLO     ,   SEC50630
     7              VL      , VLSQ    , VLS     , VS      , VSS     , WASB    ,   SEC50640
     8              WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,   SEC50650
     9              WBL     , WGB     , WG      , WGS     , WI      , WIMS          SEC50660
      COMMON        WOM     , WOMS    , X       , X10     , X11     , XCLK    ,   SEC50670
     1              XINT    , XP      , XS      , XX      , XXA     , YI      ,   SEC50680
     2              YIS     , YO      , YOS     , ZZZ     , NSTMT                   SEC50690
      DIMENSION PL(10)                                                              SEC50700
       DIMENSION NDRAY(75)                                                          SEC50710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                            SEC50720
     1      C(6),AC(2,75),XXA(3),DSRAY(100),DSRAY1(100),TERAY(100),TBRAYSEC50730
     2 1(100),DRAY(75),NC(1M),DINT(M)                                               SEC50740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                                SEC50750
      IF(NSTMT-70) 1,70,2                                                           SEC50760
    1 CALL DUMP                                                                     SEC50770
    2 IF(NSTMT-100) 1,100,3                                                         SEC50780
    3 IF(NSTMT-1400) 1,1400,1                                                       SEC50790
C     ********** STATEMENT NO. 70  ******************************
C     ***************************************************************
C
C   DELTA S ITERATION ROUTINE.
C
   70 CONTINUE
      NSTMT=9999
16004 CONTINUE
      IF(S+DS1)25070,25060,25070
25060 CONTINUE
      S=1.0E-8
C     FOLLOWING STATEMENT SIMPLIFIED BY UNIVAC.
C     SO=SIGN(1.0,DP*ZZZ) ... ETC.
25070 CONTINUE                                                                  SEC51010
      IF(SOP) 2470,2399,2470                                                    SEC51020
 2470 CONTINUE                                                                  SEC51030
      DSMIN=1.0E-6-2.0*(S*(1.0+8)/8)                                            SEC51040
      DSMAX=1.0E+8-1.0E-6                                                       SEC51050
      DSLIM=DSMIN                                                               SEC51060
      IF(DP) 3000,3010,3010                                                     SEC51070
 3000 CONTINUE                                                                  SEC51080
      DSLIM=DSMAX                                                               SEC51090
 3010 CONTINUE                                                                  SEC51100
      IJH=1                                                                     SEC51110
      SM=0.0                                                                    SEC51120
      GO TO 16000                                                               SEC51130
 3030 CONTINUE                                                                  SEC51140
      IJH=2                                                                     SEC51150
      RESO=SOSM                                                                 SEC51160
      SMJ1=SM                                                                   SEC51170
      SOJ1=SO                                                                   SEC51180
      SM=DSLIM                                                                  SEC51190
      GO TO 16000                                                               SEC51200
 3031 CONTINUE                                                                  SEC51210
      PSLIM=SOSM                                                                SEC51220
      SMJ2=SM                                                                   SEC51230
      SOJ2=SO                                                                   SEC51240
      IF(RESO*PSLIM)3090,3060,3060                                              SEC51250
 3060 CONTINUE                                                                  SEC51260
      WRITE (6,3061) DSLIM,DP                                                   SEC51270
      GO TO 3090                                                                SEC51280
 3071 CONTINUE                                                                  SEC51290
      RESZ=SOSM                                                                 SEC51300
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      SZO=SO                                                            SBC5 1210
      SZM=SM                                                            SBC5 1220
      HOPE=RESC*RESZ                                                    SBC5 1230
      IF(HOPE) 3080,3085,3085                                           SBC5 1240
 3080 CONTINUE                                                          SBC5 1250
      RSLIM=RESZ                                                        SBC5 1260
      DSLIM=SZM                                                         SBC5 1270
      SOJ2=SZO                                                          SBC5 1280
      GO TO 3090                                                        SBC5 1290
 3085 CONTINUE                                                          SBC5 1300
      RESO=RESZ                                                         SBC5 1310
      SMJ1=SZM                                                          SBC5 1320
      SOJ1=SZO                                                          SBC5 1330
 3090 CONTINUE                                                          SBC5 1340
      SM=(SMJ1+DSLIM)/2.0                                               SBC5 1350
      IJH=0                                                             SBC5 1360
16000 CONTINUE                                                          SBC5 1370
      IF(ABS(SM)-SMIN) 1390,1390,1391                                   SBC5 1380
 1390 CONTINUE                                                          SBC5 1390
      SM=-SIGN(SMIN,DP)                                                 SBC5 1400
 1391 AM=1.0+(R*SM)/(1.0+R)                                             SBC5 1410
      BM=1.0-SM/(1.0+R)                                                 SBC5 1420
      DVBSQ=(-V1/AM)-(V2/BM)                                            SBC5 1430
      VBMSQ=VBSQ+DVBSQ/2.0                                              SBC5 1440
C                                                                       SBC5 1450
C   WRITE DIAGNOSTIC IF VBM NON-POSITIVE.                               SBC5 1460
C                                                                       SBC5 1470
      IF(VBMSQ) 1250,1250,1251                                          SBC5 1480
 1250 CONTINUE                                                          SBC5 1490
      WRITE (6,4250) SM,AM,BM,V1,V2,VBSQ,DVBSQ,R,VBMSQ                  SBC5 1500
      LL=18                                                             SBC5 1510
      GO TO 1482                                                        SBC5 1520
C                                                                       SBC5 1530
C   COMPUTE VBM                                                         SBC5 1540
C                                                                       SBC5 1550
 1251 VBM=SQRT(VBMSQ)                                                   SBC5 1560
      REM=ZI*VBM*ABS(SM)                                                SBC5 1570
      IF(REM-.000001) 1258,1258,1259                                    SBC5 1580
 1258 CD=24.0/7                                                         SBC5 1590
      GO TO 71                                                          SBC5 1600
 1259 IF(REM-0.1) 1260,1260,1263                                        SBC5 1610
 1263 IF(REM-20000.) 1261,1264,1264                                     SBC5 1620
 1264 CD=0.4569                                                         SBC5 1630
      GO TO 71                                                          SBC5 1640
 1260 CD=24.0/REM                                                       SBC5 1650
      GO TO 71                                                          SBC5 1660
 1261 CD=EXP(3.271-0.8803*(ALOG(REM))+0.03417*                          SBC5 1670
     1((ALOG(REM))**2)+.001443*((ALOG(REM))**3))                        SBC5 1680
   71 CONTINUE                                                          SBC5 1690
C     ********** STATEMENT NO. 80 ***************************************SBC5 1700
C     ***************************************************************** SBC5 1710
C                                                                       SBC5 1720
C   OPTIMUM SM IS TO BE USED.                                           SBC5 1730
C                                                                       SBC5 1740
   80 IF(REM-.1611) 1380,1380,1381                                      SBC5 1750
 1380 CDP=1.0                                                           SBC5 1760
      GO TO 1384                                                        SBC5 1770
 1381 IF(REM-4709.11392,1382,1383                                       SBC5 1780
 1382 CDP=1.1137+.96834*(ALOG(REM))+.004329*((ALOG(REM))**2)            SBC5 1790
      GO TO 1384                                                        SBC5 1800
 1383 CDP=2.0                                                           SBC5 1810
 1384 SMLC=(C1*(BM**2))/(VBMSQ*CD )                                     SBC5 1820
      SMLD=(RHOL*(FM**2))/(RHOG*(AM**2))                                SBC5 1830
      SMLS=((RHOL*(BM**2))/(RHOG*AM*(1.0+R)))+                          SBC5 1840
     1      ((R*BM)/(1.0+R))-1.0                                        SBC5 1850
      SMLP=SMLD*(((2.0*AM)/(R*BM))+1.0)+1.0                             SBC5 1860
C     D-1 TO D                                  JHH 8/19/66             SBC5 1870
      ZZZ=SMLP*SMLS*SM+SMLD*CDP                                         SBC5 1880
      SO = -SIGN(1.0,DP*ZZZ)                                            SBC5 1890
      C2 = 2.0*SMLS*SMLD                                                SBC5 1892
      C2 = SMLC*ZZZ/C2                                                  SBC5 1894
      IF(C2.LT.0.0) C2=ABS(C2)
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      C2 = C2**0.33333                                                  SEC51890
      SO = SO*C2                                                        SEC51900
      SOSM = SO-SM                                                      SEC51910
   81 IF(ABS(SO-SM)-ESO)1481,1481,1482                                  SEC51920
 1481 NIS=NNSO                                                          SEC51930
      NNSO=0                                                            SEC51940
      REWIND 16                                                         SEC51950
      GO TO 82                                                          SEC51960
C*********THIS IS TO BYPASS ITERATION COUNTER DURING PLOTTING IJH = 4    SEC51970
 1482 CONTINUE                                                          SEC51980
11482 NNSO = NNSO + 1                                                   SEC51990
16060 IF (NNSO-NSO) 1483,1483,1490                                      SEC52000
C                                                                       SEC52010
C  STORE THIS VALUE OF DS1 AND WRITE DS1 ARRAY IF FULL.                 SEC52020
C                                                                       SEC52030
 1483 CONTINUE                                                          SEC52040
C*********DEBUGGING AID FOR BINARY CUT CONVERGENCE                      SEC52050
      DSRAY(KDS)=222222222.                                             SEC52060
      DSRAY(KDS+1) = SMJ1                                               SEC52070
      DSRAY(KDS+2) = SOJ1                                               SEC52080
      DSRAY(KDS+3) = RSSO                                               SEC52090
      DSRAY(KDS+4) = SM                                                 SEC52100
      DSRAY(KDS+5) = SO                                                 SEC52110
      DSRAY(KDS+6) = SOSM                                               SEC52120
      DSRAY(KDS+7) = DSLIM                                              SEC52130
      DSRAY(KDS+8) = SOJ2                                               SEC52140
      DSRAY(KDS+9) = RSLIM                                              SEC52150
      KDS = KDS + 10                                                    SEC52160
      IF(KDS - 100)16003,16003,1484                                     SEC52170
 1484 WRITE (16) DSRAY                                                  SEC52180
      KDSCT=KDSCT+1                                                     SEC52190
      DO 1486 I=1,100                                                   SEC52200
      DSRAY(I)=0.0                                                      SEC52210
 1486 CONTINUE                                                          SEC52220
      KDS=1                                                             SEC52230
16003 CONTINUE                                                          SEC52240
      GO TO (3030,3031,3071),IJH                                        SEC52250
C*****END OF BINARY CUT CONVERGENCE ROUTINE                             SEC52260
C                                                                       SEC52270
C    NO CONVERGENCE ON DS  -  PRINT DIAGNOSTIC AND GET ALL              SEC52280
C       PREVIOUS VALUES OF DS FROM TAPE 16  AND TEMPORARY STORAGE IN    SEC52290
C       DSRAY.    PRINT THEM ANDEXIT TO DIAGNOSTIC ROUTINE.             SEC52300
C                                                                       SEC52310
 1490 REWIND 16                                                         SEC52320
      NST=T=9999                                                        SEC52330
      WRITE (6,9490)                                                    SEC52340
 1491 IF(KDSCT)1493,1493,1492                                           SEC52350
 1492 READ (16) DSRAY1                                                  SEC52360
      WRITE (6,9491) (DSRAY1(I),I=1,100)                                SEC52370
      KDSCT=KDSCT-1                                                     SEC52380
      GO TO 1491                                                        SEC52390
 1493 WRITE (6,9491) (DSRAY(I),I=1,KDS)                                 SEC52400
      KDS=1                                                             SEC52410
      KDSCT=0                                                           SEC52420
      DO 1495 I=1,100                                                   SEC52430
      DSRAY(I)=0.0                                                      SEC52440
 1495 CONTINUE                                                          SEC52450
      LL=10                                                             SEC52460
      REWIND 16                                                         SEC52470
      GO TO 500                                                         SEC52480
C                                                                       SEC52490
C   OPTIMIZE DS AND DX.                                                 SEC52500
C                                                                       SEC52510
   82 IF(NEPO-1)2382,2381,2382                                          SEC52520
 2381 DS=0.0                                                            SEC52530
      S=SO                                                              SEC52540
      NEPO=0                                                            SEC52550
      GO TO 83                                                          SEC52560
 2382 DS=SO-SOP                                                         SEC52570
   83 SOP=SO                                                            SEC52580
      DX=(D/(0.75*RHOG*ABS(SM)*SM*CD*VRMSQ))                            SEC52590
     1      *(4633.04*DP+(((BM**2)*RHOL*DVBSQ)/2.0)                    SEC52600
```

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     2      *((RM*RHOL*VBMSQ)/(1.0*R))*(((2.0*SM*DT)/(1.0*R))-DS))          SEC52610
  100 DS1=DS                                                               SEC52620
      NSTMT=9999                                                           SEC52630
      VBSQ=VBSQ+DVBSQ                                                      SEC52640
      IF(VBSQ)300,300,301                                                  SEC52650
  300 WRITE (6,9300)                                                       SEC52660
      LL=19                                                                SEC52670
      GO TO 500                                                            SEC52680
C                                                                          SEC52690
C   STORE M*DPOINT QUANTITIES FOR NEXT END-POINT.                          SEC52700
C                                                                          SEC52710
  301 EMLM=EML                                                             SEC52720
      RHOLM=RHOL                                                           SEC52730
      DELTM=TG-TL                                                          SEC52740
      VLM=RM*VBM                                                           SEC52750
      HLAM=HLA                                                             SEC52760
      HLBM=HLB                                                             SEC52770
      RM=R                                                                 SEC52780
C                                                                          SEC52790
C   DETERMINE HEAT TRANSFER COEFFICIENT.   SEGMENTS ARE NOT                SEC52800
C     CONTINUOUS AT JUNCTIONS.                                             SEC52810
C                                                                          SEC52820
      IF(REM-1.0)304,304,305                                               SEC52830
  304 HM=(24.0*HKGM)/D                                                     SEC52840
      GO TO 309                                                            SEC52850
  305 IF(REM-25.0)306,306,307                                              SEC52860
  306 HM=.36D0.*CGM*PHOM*(ABS(SM))*VBM*                                    SEC52870
     1      ((2.2/REM)+(.48/(SQRT(REM))))                                 SEC52880
      GO TO 309                                                            SEC52890
  307 HM=(4.44*HKGM*(REM**.6))/D                                           SEC52900
C                                                                          SEC52910
C   COMPUTE MEAN BOUNDARY-LAYER PARAMETERS FOR CIRCULAR NOZZLE             SEC52920
C     OR OUTER WALL OF ANNULAR NOZZLE.                                     SEC52930
C                                                                          SEC52940
  308 THOM=THO*DTHO/2.0                                                    SEC52950
      DELOM=10.286*THOM                                                    SEC52960
      RDELOM=(300.*RHOL*VL*DELOM)/VILM                                     SEC52970
      IF(RDELOM.LT.0.0) RDELOM=ABS(RDELOM)                                 SEC52980
      CFOM=.208/((ALOG10(RDELOM)+.425)**2.584)                             SEC52990
      IF(MGEO)309,30,309                                                   SEC53000
  309 THIM=THI+DTHI/2.0                                                    SEC53010
      DELIM=10.286*THIM                                                    SEC53020
      RDELIM=(300.*RHOL*VL*DELIM)/VILM                                     SEC53030
      CFIM=.208/((ALOG10(RDELIM)+.425)**2.584)                             SEC53040
   30 NSTMT=30                                                             SEC53050
      RETURN                                                               SEC53060
 2399 NSTMT=2399                                                           SEC53070
      RETURN                                                               SEC53080
  500 NDIAG=1                                                              SEC53090
      CALL OUTPUT(NNN,LPGCT,MGEO)                                          SEC53100
      NSTMT=110                                                            SEC53110
      RETURN                                                               SEC53120
 9250 FORMAT(1HO,7X,15HNONPOSITIVE VBM/(1H ,9X,1P6E15.6))                  SEC53130
 9300 FORMAT(1HO,7X,14HNONPOSITIVE VB)                                     SEC53140
 9490 FORMAT(1HO,7X,24HCOULD NOT CONVERGE ON DS,//)                        SEC53150
 9491 FORMAT(1H ,1P10E13.4)                                                SEC53160
 3061 FORMAT(1HO,38HLIKE SIGN RESIDUES IN INTERVAL 0 TO   ,1PE12.4,        SEC53170
     1HFOR DP = ,E15.4)                                                    SEC53180
      END                                                                  SEC53190
                    SUBROUTINE SECT6                                       SEC60010
      COMMON TZZZAY                                                        SEC60020
      DIMENSION TZZZAY(11200)                                              SEC60030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRF               SEC60050
C     IT MUST BE THE FIRST COMMON BLOCK                                    SEC60060
      COMMON    A     , ABAR  , ALAM  , ALPHAB , ALPHA , ALPHMB ,          SEC60070
     1          ALPHS , AM    , AP    , AS     , AT    , BB    ,          SEC60080
     2          BB    , BETAB , BETAMB , BETA  , BETAS , BM    ,          SEC60090
     3          C     , C1    , CAG1  , CAGMB  , CAG   , CALMB  ,          SEC60100
     4 CBG1  , CAL   , CASE  , CDGMB , CDG    , CDLMB , CDL    ,          SEC60110
      COMMON   CDMS  , CDP   , CD    , CFIM   , CFIMS , CFOM   ,          SEC60120
     6          CFOMS , CGMB  , CGM   , CGMS   , CLMB  , CLM    ,          SEC60130
     7          CLMS  , CSAVE , D     , D2     , DA    , DA2E   ,          SEC60140
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     8           DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,      SEC60150
     9           DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2   ,      SEC60160
      COMMON     DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT    ,      SEC60170
     1           DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,      SEC60180
     2           DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,      SEC60190
     3           DSMAX   , DSMIN   , DSRAY1  , DTMAX   , DSRAY2  , DSRAY3  ,      SEC60200
     4           DSRES   , DS      , DSX1    , DSX2    , DTS1    , DT1B    ,      SEC60210
      COMMON     DTS     , DTMI    , DTMO    , DTM1    , DTLB    , DCL     ,      SEC60220
     6           DT      , DVRSQ   , DVGSQ   , DVLSQ   , DX      , EXI     ,      SEC60230
     7           DYD     , E0      , EDS     , EMAGB   , EMAG    , EMBGB   ,      SEC60240
     8           EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,      SEC60250
     9           EML     , EMLS    , EMM     , ESO     , FLOOR   , FUX     ,      SEC60260
      COMMON     H       , HJI     , HKAG    , HKBG    , HKGM1   , HKGM2   ,      SEC60270
     1           HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,      SEC60280
     2           HLB1    , HLOM    , HLB     , HLBS    , HM      , HMS     ,      SEC60290
     3           HOPE    , HT      , IACV    , IBLM    , IBLX    , IBM     ,      SEC60300
     4           IJH     , INT     , ISET    , IZERO   , K       , K1      ,      SEC60310
      COMMON     K2      , KAP     , KOSCT   , KOS     , KL      , KR1     ,      SEC60320
     6           KB      , KTBCT   , KTB     , KXP1    , KXP     , L       ,      SEC60330
     7           L1      , L2      , LCT1    , LCT2    , LL      , LPSCT   ,      SEC60340
     8           LSW     , MBU     , MEPO    , MPP     , NGSO    , NM      ,      SEC60350
     9 N         , NOP   , NTMT    , NACV    , NB      , NCLK    , NCOS    ,      SEC60360
      COMMON     NDIAG   , NDS     , NGG     , NIB     , NIS     , NLST    ,      SEC60370
     1           NNA     , NNB     , NNOS    , NNM     , NN2     , NN      ,      SEC60380
     2           NNSOO   , NNSO    , NNS     , NP      , NSC     , NS      ,      SEC60390
     3           P       , P10     , P11     , PAB     , PAMB    , PA      ,      SEC60400
     4           PAS     , PBB     , PBMB    , PBOB    , PBO     , PB      ,      SEC60410
      COMMON     PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,      SEC60420
     6           PL1     , PO      , PS      , PT      , Q       , QID     ,      SEC60430
     7           R1      , RA      , RAS     , RAXO    , RAX     , RB      ,      SEC60440
     8           RC      , RDELIM  , RDELOM  , RDLMS   , RDOMS   , REF     ,      SEC60450
     9           RFM     , RBMS    , RESLIM  , RESO    , RESS    , RHOGB   ,      SEC60460
      COMMON     RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,      SEC60470
     1           RIM     , RI      , RM      , ROALB   , ROAL    , ROALB   ,      SEC60480
     2           ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,      SEC60490
     3           RVB     , RV      , RVS     , S       , S1      , S2      ,      SEC60500
     4           S3      , S4      , SA      , SB      , SGN     , SIG     ,      SEC60510
      COMMON     SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,      SEC60520
     6           SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,      SEC60530
     7           SOP     , SO      , SOSM    , SS      , SZM     , SZO     ,      SEC60540
     8           T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGS     ,      SEC60550
     9           TG      , TGS     , THIM    , THIO    , THI     , THIS    ,      SEC60560
      COMMON     THOM    , THOO    , THO     , THOS    , TK      , TKI     ,      SEC60570
     1           TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,      SEC60580
     2           TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAM     ,      SEC60590
     3           VBO     , VBOS    , VBM     , VBMSQ   , VB      , VBSQ    ,      SEC60600
     4           VGS     , VGO     , VG      , VGSQ    , VGS     , VIMS    ,      SEC60610
      COMMON     VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,      SEC60620
     6           VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,      SEC60630
     7           VL      , VLSQ    , VLS     , VS      , VSS     , WAGB    ,      SEC60640
     8           WAG     , WAGS    , WAL     , WBGB    , WBG     , WBS     ,      SEC60650
     9           WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,      SEC60660
      COMMON     WOM     , WOMS    , X       , X10     , X11     , XCLK    ,      SEC60670
     1           XINT    , XP      , XS      , XX      , XXA     , YI      ,      SEC60680
     2           YIS     , YO      , YOS     , ZZZ     , NSTMT   ,               SEC60690
      DIMENSION PL(10)                                                           SEC60700
        DIMENSION RDRAY(75)                                                      SEC60710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                         SEC60720
     1      C(6),AB(2,75),XXA(3),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY2(100),SEC60730
     21(100),DRAY(75),HT(18),DIST(8)                                             SEC60740
      EQUIVALENCE (RDRAY(1),DRAY(1))                                             SEC60750
      IF(NSTMT-140) 1,140,2                                                      SEC60760
    1 CALL DUMP                                                                  SEC60770
    2 IF(NSTMT-2399) 1,2399,1                                                    SEC60780
C                                                                                SEC60790
C   COMPUTE  BARRED QUANTITIES AND ITERATE FOR CONVERGENCE ON TB.                SEC60800
C   GET INTERPOLATED PBO FROM TABLE FOR THIS TB.                                 SEC60810
C                                                                                SEC60820
  140 N=9                                                                        SEC60830
      NSTMT=9999                                                                 SEC60840
  339 NN=9                                                                       SEC60850
      CALL INTRP(PBOB,N,TB,2)                                                    SEC60860
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      IF(N)318,318,320                                                  SEC60870
  318 LL=20                                                             SEC60880
  319 WRITE (6,9318) HT(NN),TB,P                                        SEC60890
      GO TO 500                                                         SEC60900
C                                                                       SEC60910
C      COMPONENT A.   PRINT DIAGNOSTIC IF SUFFICIENTLY CLOSE TO ZERO.   SEC60920
C                                                                       SEC60930
  320 IF(ABS(1.0-H*PBOB)-.0001)321,321,323                              SEC60940
  321 WRITE (6,9320)                                                    SEC60950
      LL=20                                                             SEC60960
      GO TO 500                                                         SEC60970
C                                                                       SEC60980
C    COMPUTE PARTIAL PRESSURE OF COMPONENT A AND B AND                  SEC60990
C      PRINT DIAGNOSTIC IF EITHER NONPOSITIVE.                          SEC61000
C                                                                       SEC61010
  323 PAB=(P-PEOB)/(1.-(H*PBOB))                                        SEC61020
      IF (PAB) 31),322,322                                              SEC61030
  322 PBB = P-PAB                                                       SEC61040
      IF(PBB)312,9323,9323                                              SEC61050
C                                                                       SEC61060
C    INTERPOLATE INTO MOLECULAR WEIGHT TABLES FOR A AND B               SEC61070
C      AT THIS TEMPERATURE AND PRESSURE.                                SEC61080
C                                                                       SEC61090
 9323 N=3                                                               SEC61100
      NN=3                                                              SEC61110
      CALL INTERP(WAGB,N,TB,PAB)                                        SEC61120
      IF(N)325,325,327                                                  SEC61130
  325 LL=22                                                             SEC61140
      WRITE (6,9318) HT(NN),TB,PAB                                      SEC61150
      GO TO 500                                                         SEC61160
  327 N=4                                                               SEC61170
      NN=4                                                              SEC61180
      CALL INTERP(WBGB,N,TB,PBB)                                        SEC61190
      IF(N)329,329,330                                                  SEC61200
  329 LL=23                                                             SEC61210
      WRITE (6,9318) HT(NN),TB,PBB                                      SEC61220
      GO TO 500                                                         SEC61230
  310 WRITE (6,9310)                                                    SEC61240
      LL=20                                                             SEC61250
      GO TO 500                                                         SEC61260
  312 WRITE (6,9312)                                                    SEC61270
      LL=21                                                             SEC61280
      GO TO 500                                                         SEC61290
C                                                                       SEC61300
C    COMPUTE MEAN MOLECULAR WEIGHT.                                     SEC61310
C                                                                       SEC61320
  330 WGB=((WAGB*PAB)+(WBGB*PBB))/P                                     SEC61330
C                                                                       SEC61340
C    COMPUTE ALPHA AND BETA.                                            SEC61350
C                                                                       SEC61360
      ALPHAB=((WAL/WBL)*H*PAB)/                                         SEC61370
     1       (1.0+((WAL/WBL)-1.0)*H*PAB)                                SEC61380
      BETAB=(WEGB*PBB)/(WGB*P)                                          SEC61390
C                                                                       SEC61400
C    CHECK DENOMINATOR OF EQUATION FOR R AND PRINT                      SEC61410
C      DIAGNOSTIC IF SUFFICIENTLY CLOSE TO ZERO.                        SEC61420
C                                                                       SEC61430
      TK=(1.0-(1.0+RC)*ALPHAB)                                          SEC61440
      TKT=ABS(TK)                                                       SEC61450
      IF(TKT-.0001) 333,335,335                                         SEC61460
  333 WRITE (6,9333)                                                    SEC61470
      LL=24                                                             SEC61480
      GO TO 500                                                         SEC61490
C                                                                       SEC61500
C    COMPUTE BARRED FLOW PARAMETERS.                                    SEC61510
C                                                                       SEC61520
  335 BB=(BC-(1.0+BC)*BETAB)/TK                                         SEC61530
      DEMGB=(BMT/(1.0+BB))-BMG                                          SEC61540
      BMGB=BMG+DEMGB                                                    SEC61550
      BMLB=BB*BMGB                                                      SEC61560
      DEMAGB=((BMTB*WAGB*PAB)/(WGB*P))-BMAG                             SEC61570
      DEMBGB=((BMGB*WBGB*PBB)/(WGB*P))-BMBG                             SEC61580
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      EMAGB=EMAG+DEMAGB                                                 SEC6 1590
      EMBGB=EMBG+DEMBGB                                                 SEC6 1600
      DTGB=TB-TG                                                        SEC6 1610
      TLMB=(TL+TB)/2.0                                                  SEC6 1620
      TGMB=(TG+TB)/2.0                                                  SEC6 1630
      PAMB=(PA+PAB)/2.0                                                 SEC6 1640
      PBMB=(PB+PBB)/2.0                                                 SEC6 1650
C                                                                       SEC6 1660
C   INTERPOLATE INTO SPECIFIC HEAT TABLES FOR                           SEC6 1670
C        CALMB  -  SPECIFIC HEAT - LIQUID A                             SEC6 1680
C        CBLMB  -  SPECIFIC HEAT - LIQUID B                             SEC6 1690
C        CAGMB  -  SPECIFIC HEAT - GAS A                                SEC6 1700
C        CBGMB  -  SPECIFIC HEAT - GAS B                                SEC6 1710
C                                                                       SEC6 1720
      N=5                                                               SEC6 1730
      NN=5                                                              SEC6 1740
      CALL INTRP(CALMB,N,TLMB,P )                                       SEC6 1750
      IF(N) 340,340,341                                                 SEC6 1760
  340 WRITE (6,9136) HT(NN),TLMB,P                                      SEC6 1770
      LL=25                                                             SEC6 1780
      GO TO 500                                                         SEC6 1790
  341 N=6                                                               SEC6 1800
      NN=6                                                              SEC6 1810
      CALL INTRP(CBLMB,N,TLMB,P)                                        SEC6 1820
      IF(N) 340,340,343                                                 SEC6 1830
  343 N=1                                                               SEC6 1840
      NN=1                                                              SEC6 1850
      CALL INTRP(CAGMB,N,TGMB,PAB)                                      SEC6 1860
      IF(N) 344,344,345                                                 SEC6 1870
  344 LL=25                                                             SEC6 1880
      WRITE (6,9136) HT(NN),TGMB,PAB                                    SEC6 1890
      GO TO 500                                                         SEC6 1900
  345 N=2                                                               SEC6 1910
      NN=2                                                              SEC6 1920
      CALL INTRP(CBGMB,N,TGMB,PBB)                                      SEC6 1930
      IF(N) 346,346,347                                                 SEC6 1940
  346 LL=25                                                             SEC6 1950
      WRITE (6,9136) HT(NN),TGMB,PBB                                    SEC6 1960
      GO TO 500                                                         SEC6 1970
  347 ALPHMB=(ALPHA+ALPHAB)/2.0                                         SEC6 1980
      BETAMB=(BETA+BETAB)/2.0                                           SEC6 1990
      CLMB=(ALPHMB*CALMB)+(1.0-ALPHMB)*CBLMB                            SEC6 2000
      CGMB=(1.0-BETAMB)*CAGMB+BETAMB*CBGMB                              SEC6 2010
      DTLB=(-1.0/(EMB*CLMB))*((CGMB*DTGB)+                              SEC6 2020
     1      ((VBSQ-VG**2+2.0*(VBSQ-VL**2))/50072.9)+                    SEC6 2030
     2      ((DEMAGB/EMGB)*(HLA+CAG*(TG-TL)))+                          SEC6 2040
     3      ((DEMBGB/EMGB)*(HLB+CBG*(TG-TL)))+                          SEC6 2050
     4      ((DEMGB/EMGB)*(((VG**2)-(VL**2))/50072.9)))                 SEC6 2060
C                                                                       SEC6 2070
C   TEST FOR CONVERGENCE ON TB.                                         SEC6 2080
C                                                                       SEC6 2090
      IF((ABS((TB-TL)-DTLB))-EB) 141,141,350                            SEC6 2100
  350 NNB=NNB+1                                                         SEC6 2110
      IF(NNB-NE) 351,351,354                                            SEC6 2120
C                                                                       SEC6 2130
C   SAVE THIS VALUE OF TB FOR POSSIBLE NON-CONVERGENCE.                 SEC6 2140
C                                                                       SEC6 2150
  351 TB=TL+DTLB                                                        SEC6 2160
      TBRAY(KTB)=TB                                                     SEC6 2170
      KTB=KTB+1                                                         SEC6 2180
      IF(KTB-100) 140,140,352                                           SEC6 2190
  352 WRITE (14) TBRAY                                                  SEC6 2200
      DO 353 I=1,100                                                    SEC6 2210
      TBRAY(I)=0.0                                                      SEC6 2220
  353 CONTINUE                                                          SEC6 2230
      KTB=1                                                             SEC6 2240
      KTBCT=KTBCT+1                                                     SEC6 2250
       GO TO 140                                                        SEC6 2260
C                                                                       SEC6 2270
C   NO CONVERGENCE ON TB AND ITERATION MAXIMUM REACHED.                 SEC6 2280
C      PRINT DIAGNOSTIC AND ALL VALUES OF TB FOUND.                     SEC6 2290
C                                                                       SEC6 2300
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  354 WRITE (6,9352)                                                    SEC6 2310
  399 IF(KTBCT)403,403,400                                              SEC6 2320
  400 READ (14) TBRAY1                                                  SEC6 2330
      WRITE (6,9491) (TBRAY1(I),I=1,100)                                SEC6 2340
      KTBCT=KTBCT-1                                                     SEC6 2350
      GO TO 399                                                         SEC6 2360
  403 WRITE (6,9491) (TBRAY(I),I=1,KTB)                                 SEC6 2370
C                                                                       SEC6 2380
C   CLEAR TB SAVE ARRAY.                                                SEC6 2390
C                                                                       SEC6 2400
      KTB=1                                                             SEC6 2410
      KTBCT=0                                                           SEC6 2420
      DO 405 I=1,100                                                    SEC6 2430
      TBRAY(I) =0.0                                                     SEC6 2440
  405 CONTINUE                                                          SEC6 2450
      LL=26                                                             SEC6 2460
      GO TO 500                                                         SEC6 2470
C   STORE NUMBER OF ITERATIONS REQUIRED TO CONVERGE ON TB.              SEC6 2480
C                                                                       SEC6 2490
C     ********** STATEMENT NO. 140 **********                          SEC6 2500
C     ********************************************************************SEC6 2510
  141 NIB=NNB                                                           SEC6 2520
      NNB=1                                                             SEC6 2530
C                                                                       SEC6 2540
C   COMPUTE DENSITY OF GAS MIXTURE.                                     SEC6 2550
C                                                                       SEC6 2560
      RHOGB=(WGB*P)/(10.732*TB)                                         SEC6 2570
C                                                                       SEC6 2580
C   INTERPOLATE FOR DENSITIES OF LIQUIDS A AND B.                       SEC6 2590
C                                                                       SEC6 2600
      N=10                                                              SEC6 2610
      NN=10                                                             SEC6 2620
      CALL INTRP(ROALB,N,TB,P)                                          SEC6 2630
      LL=27                                                             SEC6 2640
      IF(N)319,319,360                                                  SEC6 2650
  360 N=11                                                              SEC6 2660
      NN=11                                                             SEC6 2670
      CALL INTRP(ROBLB,N,TB,P)                                          SEC6 2680
      LL=27                                                             SEC6 2690
      IF(N)319,319,363                                                  SEC6 2700
C                                                                       SEC6 2710
C   COMPUTE DENSITY OF LIQUID MIXTURE.                                  SEC6 2720
C                                                                       SEC6 2730
  363 RHOLB=1.0/((ALPHAB/ROALB)+((1.0-ALPHAB)/(ROBLB)))                 SEC6 2740
      ABAR=((144.)*EMGB)*(1.0/RHOGB+RB/RHOLB))/VB                       SEC6 2750
      RVB=RHOLB/(RB*RHOGB)                                              SEC6 2760
      Q=(RHOLB*ABAR*VB)/(144.0*EMLB)                                    SEC6 2770
C                                                                       SEC6 2780
CC    INTERPOLATE INTO VISCOSITY TABLES FOR LIQUID A AND B.             SEC6 2790
C                                                                       SEC6 2800
      N=14                                                              SEC6 2810
      NN=14                                                             SEC6 2820
      CALL INTRP(VIALB,N,TB,P)                                          SEC6 2830
      LL=28                                                             SEC6 2840
      IF(N)319,319,366                                                  SEC6 2850
  366 N=15                                                              SEC6 2860
      NN=15                                                             SEC6 2870
      CALL INTRP(VIBLB,N,TB,P)                                          SEC6 2880
      IF(N)369,369,370                                                  SEC6 2890
  369 LL=28                                                             SEC6 2900
      GO TO 319                                                         SEC6 2910
  370 VILB=ALPHAB*VIALB*(1.0-ALPHAB)*VIBLB                              SEC6 2920
      REF=(8617.2*EMLB)/(VILB*(SQRT(ABAR)))                            SEC6 2930
C  ENTER CURRENT VALUES OF A AND P INTO A VS P TABLE                    SEC6 2940
C                                                                       SEC6 2950
  529 NSTMT=529                                                         SEC6 2960
      RETURN                                                            SEC6 2970
C                                                                       SEC6 2980
C     ********************************************************************SEC6 2990
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$SEC6 3000
C   FIND GOOD APPROXIMATION FOR DS1 TO USE IN SUCCESSIVE                SEC6 3010
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C     SUBSTITUTION ROUTINE AT STEP 90.                                  SEC6 1050
C                                                                       SEC6 1060
 2399 KDSCT=0                                                           SEC6 1070
      NSIMT=9999                                                        SEC6 1080
      IBLW=0                                                            SEC6 1090
      KDS=1                                                             SEC6 1100
      NNDS=0                                                            SEC6 1110
      SGN=0.5                                                           SEC6 1120
      DSMIN=1.0E-6-2.0*(S+(1.0+R)/R)                                    SEC6 1130
      DSMAX=1.0+R-1.0E-6                                                SEC6 1140
12399 CONTINUE                                                          SEC6 1150
      DS1=DSMIN                                                         SEC6 1160
      IBW=1                                                             SEC6 1170
      GO TO 5000                                                        SEC6 1180
 2401 CONTINUE                                                          SEC6 1190
      DSX1=DS1                                                          SEC6 1200
      DSRES1=DSRES                                                      SEC6 1210
      DS1=DSMAX                                                         SEC6 1220
      IBW=2                                                             SEC6 1230
      GO TO 5000                                                        SEC6 1240
 2402 CONTINUE                                                          SEC6 1250
      DSX2=DS1                                                          SEC6 1260
      DSRES2=DSRES                                                      SEC6 1270
      IF(IBLX) 12402,2403,12402                                         SEC6 1280
12402 CONTINUE                                                          SEC6 1290
      DS1=DSAVE                                                         SEC6 1300
      GO TO 12403                                                       SEC6 1310
 2403 CONTINUE                                                          SEC6 1320
      DS1=DSX1-DSRES1*(DSX2-DSX1)/(DSRES2-DSRES1)                       SEC6 1330
      IBLX=1                                                            SEC6 1340
12403 CONTINUE                                                          SEC6 1350
      IBW=3                                                             SEC6 1360
      GO TO 5000                                                        SEC6 1370
 2404 CONTINUE                                                          SEC6 1380
      IF(DSRES*DSRES1) 2405,2406,2406                                   SEC6 1390
 2405 CONTINUE                                                          SEC6 1400
      DSRES2=DSRES                                                      SEC6 1410
      DSX2=DS1                                                          SEC6 1420
      SGN=-1.0*SGN                                                      SEC6 1430
      GO TO 2407                                                        SEC6 1440
 2406 CONTINUE                                                          SEC6 1450
      DSRES1=DSRES                                                      SEC6 1460
      DSX1=DS1                                                          SEC6 1470
 2407 CONTINUE                                                          SEC6 1480
      IF(SGN) 12407,2408,2408                                           SEC6 1490
12407 CONTINUE                                                          SEC6 1500
      DS1=DSX2                                                          SEC6 1510
      GO TO 2409                                                        SEC6 1520
 2408 CONTINUE                                                          SEC6 1530
      DS1=DSX1                                                          SEC6 1540
 2409 CONTINUE                                                          SEC6 1550
      DS1=DS1+SGN                                                       SEC6 1560
      IF(DS1-DSMAX) 2410,2410,5060                                      SEC6 1570
 2410 CONTINUE                                                          SEC6 1580
      IF(DS1-DSMIN) 5060,12410,12410                                    SEC6 1590
12410 CONTINUE                                                          SEC6 1600
      IBW=4                                                             SEC6 1610
      GO TO 5000                                                        SEC6 1620
12411 CONTINUE                                                          SEC6 1630
      IF(SGN) 12414,12412,12412                                         SEC6 1640
12412 CONTINUE                                                          SEC6 1650
      IF(DSRES*DSRES2) 2406,12413,12413                                 SEC6 1660
12413 CONTINUE                                                          SEC6 1670
      DSRES2=DSRES                                                      SEC6 1680
      DSX2=DS1                                                          SEC6 1690
      GO TO 12416                                                       SEC6 1700
12414 CONTINUE                                                          SEC6 1710
      IF(DSRES*DSRES1) 12417,12415,12415                                SEC6 1720
12415 CONTINUE                                                          SEC6 1730
      DSRES1=DSRES                                                      SEC6 1740
      DSX1=DS1                                                          SEC6 1750
12416 CONTINUE                                                          SEC6 1760
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      SGN=SGN/10.0                                                      SEC64370
      IBLW=IBLW+1                                                       SEC64380
      IF(IBLW-5)2403,2403,5060                                          SEC64390
12417 CONTINUE                                                          SEC64400
      DSRES2=DSRES                                                      SEC64410
      DSX2=DS1                                                          SEC64420
      GO TO 2409                                                        SEC64430
C                                                                       SEC64440
C     EVALUATE DS FOR GIVEN DS1.   TEST FOR CONVERGENCE                 SEC64450
C                                                                       SEC64460
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$SEC64470
C                                                                       SEC64480
 5000 CONTINUE                                                          SEC64490
      SM=S*DS1/2.0                                                      SEC64500
      AM=1.0+(R*SM)/(1.0+R)                                             SEC64510
      BM=1.0-SM/(1.0+R)                                                 SEC64520
      DVBSQ=(-V1/AM)-(V2/BM)                                            SEC64530
      VBMSQ=VBSQ+DVBSQ/2.0                                              SEC64540
      IF(VBMSQ)6000,5001,5001                                           SEC64550
 6000 CONTINUE                                                          SEC64560
      WRITE (6,3001) SM,S,DS1,AM,R,BM,DVBSQ,V1,V2,VBMSQ,VBM             SEC64570
 5001 CONTINUE                                                          SEC64580
      VBM=SQRT(VBMSQ)                                                   SEC64590
      REM=R1*VBM*ABS(SM)                                                SEC64600
      IF(REM-.000001)5015,5015,5005                                     SEC64610
 5005 IF(REM-0.1)5020,5020,5010                                         SEC64620
 5010 IF(REM-20000.)5030,5025,5025                                      SEC64630
 5015 CD=2.4E07                                                         SEC64640
      GO TO 5035                                                        SEC64650
 5020 CD=24.0/REM                                                       SEC64660
      GO TO 5035                                                        SEC64670
 5025 CD=0.4569                                                         SEC64680
      GO TO 5035                                                        SEC64690
 5030 CD=EXP(3.271-0.8893*(ALOG(REM))+0.01417*                          SEC64700
     1((ALOG(REM))**2)+.001443*((ALOG(REM))**3))                        SEC64710
 5035 CONTINUE                                                          SEC64720
      DSMP=-((S1*ABS(SM)*SM*CD)/BM)+(S2/(BM*VBMSQ))                     SEC64730
     1+((S1*BM*DVBSQ)/VBMSQ)+S4*SM                                      SEC64740
      DSRES=SMF-DS1                                                     SEC64750
      IF(ABS(DSRES)-EDS)91,91,5040                                      SEC64760
 5040 DSRAY(KDS)=DS1                                                    SEC64770
      DSRAY(KDS+1)=DSRES                                                SEC64780
      KDS=KDS+2                                                         SEC64790
      IF(KDS-100)5055,5055,5045                                         SEC64800
 5045 WRITE (16) DSRAY                                                  SEC64810
      KDSCT=KDSCT+1                                                     SEC64820
      DO 5050 L=1,100                                                   SEC64830
 5050 DSRAY(L)=0.0                                                      SEC64840
      KDS=1                                                             SEC64850
 5055 NNDS=NNDS+1                                                       SEC64860
      IF(NNDS-NDS)5070,5070,5060                                        SEC64870
 5060 WRITE (6,5065) DSX1,DSX2,DS1,DSRES1,DSRES2,DSRES                  SEC64880
      LL=16                                                             SEC64890
      GO TO 1490                                                        SEC64900
 5070 CONTINUE                                                          SEC64910
      GO TO (2401,2402,2404,12411,2405,2407,2409),IBW                   SEC64920
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$SEC64930
C                                                                       SEC64940
C   COMPUTE NEXT APPROXIMATION TO DS.                                   SEC64950
C                                                                       SEC64960
   91 NIS=NNDS                                                          SEC64970
      IBLX=1                                                            SEC64980
      DS=DS1                                                            SEC64990
      DSAVE=DS1                                                         SEC65000
      NNDS=0                                                            SEC65010
      GO TO 100                                                         SEC65020
 1490 NSIMT=1490                                                        SEC65030
      RETURN                                                            SEC65040
  100 NSIMT=100                                                         SEC65050
      RETURN                                                            SEC65060
  500 NDIAG=1                                                           SEC65070
      CALL OUTPUT(NNN,LPGCT,NGEO)                                       SEC65080
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      NSTST=110                                                                 SEC64500
      RETURN                                                                    SEC64510
 5065 FORMAT(1HO,7X,51HNO DS CONVERGENCE.  COULD DETECT NO SIGN CHANGE  SEC64520
     1IN ,I4HRESIDUALS OF F(DS).  VALUES FOLLOW  /(10X,1P6E15.6))       SEC64530
 9001 FORMAT(1HO,10X,20HNEGATIVE VBMSQ,SECT6 /(1X,1P8E15.6))            SEC64540
 9136 FORMAT(1HO,7X,17HOUTSIDE RANGE OF  , A6,7H TABLE.,5X,             SEC64550
     1HT = ,1PE12.4,5X,4HP = ,E12.4)                                    SEC64560
 9310 FORMAT(1HO,7X,12HNEGATIVE PAB)                                    SEC64570
 9312 FORMAT(1HO,7X,12HNEGATIVE PBB)                                    SEC64580
 9318 FORMAT(1HO,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,               SEC64590
     1HT = ,1PE12.4,5X,4HP = ,E12.4)                                    SEC64600
 9320 FORMAT(1HO,7X,12HINFINITE PAB)                                    SEC64610
 9333 FORMAT(1HO,7X,14HNONPOSITIVE PB)                                  SEC64620
 9352 FORMAT(1HO,7X,24HCOULD NOT CONVERGE ON TB)                        SEC64630
 9491 FORMAT(1H ,1P10E13.4)                                             SEC64640
      END                                                               SEC64650
                    SUBROUTINE THROAT                                   THR00010
      COMMON TZZZAY                                                     THR00020
      DIMENSION TZZZAY(11200)                                           THR00030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP            THR00040
C     IT MUST BE THE FIRST COMMON BLOCK                                 THR00050
      COMMON    A       , ABAR    , ALAM    , ALPHAB , ALPHA   , ALPHMB ,  THR00070
     1          ALPHS   , AM      , AP      , AS     , AT      , BA      ,  THR00080
     2          BB      , BETAB   , BETAMB  , BETA   , BETAS   , BM      ,  THR00090
     3          C       , C1      , CAG1    , CAGMB  , CAG     , CALMB   ,  THR00100
     4 CBG1    , CAL     , CASE    , CBGMB   , CBG    , CBLMB  , CBL     ,  THR00110
      COMMON    CDMS    , CDP     , CD      , CFIM   , CFIMS  , CFDM    ,  THR00120
     6          CFOMS   , CGMB    , CGM     , CGMS   , CLMB   , CLM     ,  THR00130
     7          CLMS    , CSAVE   , D       , D2     , DA     , DATE    ,  THR00140
     8          DD      , DELIM   , DELI    , DELIS  , DELOM  , DELO    ,  THR00150
     9          DELOS   , DELSI   , DELSO   , DELTM  , DELT   , DELV2   ,  THR00160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG  , DEMGB  , DIST    ,  THR00170
     1          DLSIS   , DLSOS   , DO      , DP1    , DP     , DRAY    ,  THR00180
     2          DPI     , DRO     , DR      , DS1    , DSAVE  , DSLIM   ,  THR00190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY  , DSRRS1 , DSRRS2  ,  THR00200
     4          DSRES   , DS      , DSX1    , DSX2   , DTGB   , DTHB    ,  THR00210
      COMMON    DTG     , DTHI    , DTHO    , DTL1   , DTLB   , DTL     ,  THR00220
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ  , DX     , DYI     ,  THR00230
     7          DYO     , EB      , EBS     , EMG3   , EMAG   , EMDGB   ,  THR00240
     8          EMGB    , EMG     , EMGS    , EMLB   , EMLM   , EMLS    ,  THR00250
     9          EML     , EMLS    , EMT     , EPS    , FLEEP  , FOC     ,  THR00260
      COMMON    H       , HDT     , HKAG    , HKBG   , HKGM1  , HKGM2   ,  THR00270
     1          HKGM    , HKGMS   , HLA1    , HLAM   , HLA    , HLAS    ,  THR00280
     2          HLD1    , HLIM    , HL6     , HL66   , IM     , IMS     ,  THR00290
     3          HOPE    , HT      , IACV    , IBLA   , IBLB   , IBS     ,  THR00300
     4          IGM     , INT     , ISET    , ISPRO  , K      , K1      ,  THR00310
      COMMON    K2      , KAP     , KDSCT   , KDS    , KL     , KM1     ,  THR00320
     6          KP      , KTJCT   , KTB     , KYP1   , KYP    , L       ,  THR00330
     7          L1      , L2      , LCT1    , LCT2   , LL     , LPOCT   ,  THR00340
     8          LSW     , MBU     , MFFO    , MFP    , MGFO   , MM      ,  THR00350
     9 M       , MOP     , MTHT    , NACV    , NB     , NCIK   , NCTS    ,  THR00360
      COMMON    NDIAG   , NDS     , NGG     , NIB    , NIS    , NLIT    ,  THR00370
     1          NMA     , NNB     , NNDS    , NON    , NOP    , NP      ,  THR00380
     2          NNSOO   , NNSO    , NNS     , NP     , NSO    , NS      ,  THR00390
     3          P       , P10     , P11     , PAB    , PAMB   , PA      ,  THR00400
     4          PAS     , PBB     , PBMB    , PBOB   , PDO    , PB      ,  THR00410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI    , PINF   , PL      ,  THR00420
     6          PL1     , PO      , PS      , PT     , Q      , QIO     ,  THR00430
     7          R1      , RA      , RAS     , RAXO   , RAX    , RB      ,  THR00440
     8          RC      , RDELIM  , RDELOM  , RDIMS  , RDOMS  , REP     ,  THR00450
     9          REM     , RFMS    , RFSLIM  , RESO   , RESZ   , RHOGB   ,  THR00460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM  , RHOL   , RHOLS   ,  THR00470
     1          RLM     , RI      , RM      , RPALB  , RPAL   , RORLD   ,  THR00480
     2          RORL    , RORM    , RO      , R      , RSLIM  , RS      ,  THR00490
     3          RVB     , RV      , RVS     , S      , S1     , S2      ,  THR00500
     4          SJ      , SM      , SA      , SB     , SGN    , SIG     ,  THR00510
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2   , SMLC   , SMLD    ,  THR00520
     6          SMLS    , SMLP    , SMLG    , SM     , SOJ1   , SOJ2    ,  THR00530
     7          SOP     , SO      , SOSM    , SS     , SSM    , S20     ,  THR00540
     8          T       , TB      , TBRAY   , TBRAY1 , TGM3   , TGO     ,  THR00550
     9          TG      , TGS     , THIM    , THIO   , THT    , THIS    ,  THR00560
      COMMON    THOM    , THOO    , THO     , THOS   , TK     , TRT     ,  THR00570
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     1          TLMB   , TLO    , TL     , TLS    , TST    , TWIM   ,     THRO0580
     2          TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAR    ,     THRO0590
     3          VBD    , VBDS   , VBM    , VBMSQ  , VB     , VBSQ   ,     THRO0600
     4          VBS    , VGD    , VG     , VGSQ   , VGS    , VIAG   ,     THRO0610
      COMMON    VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIBM   ,     THRO0620
     6          VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLD    ,     THRO0630
     7          VL     , VLSQ   , VLS    , VS     , VSS    , WAGB   ,     THRO0640
     8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,     THRO0650
     9          WBL    , WGD    , WG     , WGS    , WIM    , WIMS   ,     THRO0660
      COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLR   ,     THRO0670
     1          XINT   , XP     , XS     , XX     , XXA    , YI     ,     THRO0680
     2          YIS    , YO     , YOS    , ZZZ    , NSTMT                 THRO0690
      DIMENSION PL(10)                                                    THRO0700
      DIMENSION NDRAY(75)                                                 THRO0710
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),                  THRO0720
     1     C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TPRAY(100),TBRAY THRO0730
     2 1(100),DRAY(75),HT(14),DINT(8)                                     THRO0740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                      THRO0750
      IF(NSTMT-110)1,110,1                                                THRO0760
    1 CALL DUMB                                                           THRO0770
C                                                                         THRO0780
CCC                                                                       THRO0790
C     PRINT THROAT CONDITIONS.                                            THRO0800
C                                                                         THRO0810
  110 WRITE (6,9110)                                                      THRO0820
      NSTMT=999                                                           THRO0830
      WRITE (6,1001) XS,PS,RS,VBS,AS,TGS,TLS,VGS,VLS                      THRO0840
 1175 WRITE (6,1002) VSS,SS,DD,RVS,WAS,ALPHS,BETAS,                       THRO0850
     1     SWGS,RMLS                                                     THRO0860
 1176 WRITE (6,1003) RWOGS,RHOLS,WAGS,WBGS,WGS,                           THRO0870
     1     PAS,PBS,HLAS,HLBS                                             THRO0880
 1177 WRITE (6,1004) SIGS,CGMS,CLMS,VIGMS,VILMS,                          THRO0890
     1     HKGMS,RAMS,CDMS,HMS                                           THRO0900
 1178 WRITE(6,1007) YCS,WOMS,THOS,DELOS,DLSOS,                            THRO0910
     1     PDOMS,CPOMS,TWOMS,VBDS                                        THRO0920
      IF(MGRO-1)497,1180,497                                              THRO0930
C                                                                         THRO0940
CCC   LINE 8 OF OUTPUT CONTAINS ADDITIONAL QUANTITIES COMPUTED  FOR       THRO0950
CCC     ANNULAR NOZZLE.                                                   THRO0960
C                                                                         THRO0970
 1180 WRITE (6,1008) YIS,WIMS,THIS,DELTS,DLSIS,RDIMS,                     THRO0980
     1     CPIMS,TWIMS                                                   THRO0990
  497 NSTMT=497                                                           THRO1000
      RETURN                                                              THRO1010
C                                                                         THRO1020
CCC   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.                      THRO1030
C                                                                         THRO1040
 1001 FORMAT(1HO,13X,1HX,13X,1HP,13X,1HS,12X,2HVB,13X,1HA,12X,2HTG,12X,  THRO1050
     12HTL,12X,2HVG,12X,2HVL,/,9X,1P8E14.4)                               THRO1060
 1002 FORMAT(1HO,12X,2HVS,11X,1HS,13X,1D,12X,2HRV,12X,2HSA,9X,           THRO1070
     15HALPHA,10X,4HBETA,12X,2HMS,12X,2HM,/,9X,1P8E14.4)                  THRO1080
 1003 FORMAT(1HO,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,       THRO1090
     112X,2HSA,12X,2HPS,12X,2HLA,12X,2HLB,/,9X,1P8E14.4)                  THRO1100
 1004 FORMAT(1HO,9X,5HSIGMA,11X,4HCGM,11X,4HCLM,10X,5HVIGM,10X,          THRO1110
     14HVILM,11X,3HKGM,11X,3HRAM,11X,3HCDM,12X,2HM,/,9X,1P8E14.4)         THRO1120
 1007 FORMAT(1HO,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,     THRO1130
     19X,5HPRODC,10X,4HCPOM,10X,4HTWOM,11X,3HVBD,/,9X,1P8E14.4          ) THRO1140
 1008 FORMAT(1HO,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*I,9X,  THRO1150
     15HREDIM,10X,4HCPIM,10X,4HTWIM,/,9X,1P8E14.4)                        THRO1160
 9110 FORMAT(1HO,7X,24HTHROAT CONDITIONS FOLLOW)                          THRO1170
      END                                                                 THRO1180
                    SUBROUTINE DIAGNO                                     DIAG0010
      COMMON IZZZAY                                                       DIAG0020
      DIMENSION IZZZAY(11200)                                             DIAG0030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP              DIAG0040
C     IT MUST BE THE FIRST COMMON BLOCK                                   DIAG0050
      COMMON    A      , ABAR   , ALAM   , ALPHAB , ALPHA  , ALPHMB ,     DIAG0070
     1          ALPHS  , AM     , AP     , AS     , AT     , BA     ,     DIAG0080
     2          BB     , BETAB  , BETAMB , BETA   , BETAS  , BM     ,     DIAG0090
     3          C      , C1     , CAG1   , CAGMB  , CAG    , CALMB  ,     DIAG0100
     4 CBG1   , CAL    , CASZ   , CBGMB  , CBG    , CBLMB  , CBL    ,     DIAG0110
      COMMON    CDMS   , CDP    , CD     , CPIM   , CPIMS  , CPOM   ,     DIAG0120
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      6           CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,      DIAG0130
      7           CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,      DIAG0140
      8           DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,      DIAG0150
      9           DELOS   , DELSI   , DFLSO   , DELTM   , DELT    , DELV2   ,      DIAG0160
       COMMON     DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT    ,      DIAG0170
      1           DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,      DIAG0180
      2           DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,      DIAG0190
      3           DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,      DIAG0200
      4           DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB    ,      DIAG0210
       COMMON     DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,      DIAG0220
      6           DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DXI     ,      DIAG0230
      7           DXO     , EB      , EDS     , EMAGB   , EMAG    , EMBGB   ,      DIAG0240
      8           EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,      DIAG0250
      9           EML     , EMLS    , EMT     , ESO     , FLOSP   , FUX     ,      DIAG0260
       COMMON     H       , HJI     , HMAG    , HMBG    , HXGM1   , HXGM2   ,      DIAG0270
      1           HXGM    , HXGMS   , HLA1    , HLAM    , HLA     , HLAS    ,      DIAG0280
      2           HLB1    , HLBM    , HLB     , HLDS    , HM      , HMS     ,      DIAG0290
      3           HOPE    , HT      , IACV    , IBLW    , IBLX    , IBW     ,      DIAG0300
      4           IJH     , INT     , ISET    , IZERO   , K       , K1      ,      DIAG0310
       COMMON     K2      , KAP     , KDSCT   , KDS     , KL      , KR1     ,      DIAG0320
      6           KR      , KTBCT   , KTB     , KXP1    , KXP     , L       ,      DIAG0330
      7           L1      , L2      , LCT1    , LCT2    , LL      , LPSCT   ,      DIAG0340
      8           LSW     , MBH     , MFRO    , MFP     , MGRO    , MM      ,      DIAG0350
      9 N         MO2     , MTHT    , NACV    , NB      , NCLK    , NCTS    ,      DIAG0360
       COMMON     NDIAG   , NDS     , NGG     , NTB     , NTS     , NLST    ,      DIAG0370
      1           NNA     , NNB     , NNDS    , NNN     , NNP     , NN      ,      DIAG0380
      2           NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,      DIAG0390
      3           P       , P10     , P11     , PAB     , PAMB    , PA      ,      DIAG0400
      4           PAG     , PBB     , PBMB    , PBOB    , PBO     , PB      ,      DIAG0410
       COMMON     PBS     , PHIAB   , PHIBA   , PHI     , PIMT    , PL      ,      DIAG0420
      6           PL1     , PO      , PS      , PT      , Q       , QID     ,      DIAG0430
      7           R1      , RA      , RAS     , RAXO    , RAX     , RB      ,      DIAG0440
      8           RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , RDF     ,      DIAG0450
      9           REM     , REMS    , REGLIM  , REGO    , REGZ    , RHDGB   ,      DIAG0460
       COMMON     RHDG    , RHDGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,      DIAG0470
      1           RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,      DIAG0480
      2           ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,      DIAG0490
      3           RVB     , RV      , RVS     , S       , S1      , S2      ,      DIAG0500
      4           S3      , S4      , SA      , SB      , SGN     , SIG     ,      DIAG0510
       COMMON     SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,      DIAG0520
      6           SMLB    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,      DIAG0530
      7           SOP     , SO      , SOSM    , SS      , SZM     , SZO     ,      DIAG0540
      8           T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO     ,      DIAG0550
      9           TG      , TGS     , THIM    , THIO    , THI     , THIS    ,      DIAG0560
       COMMON     THOM    , THOO    , THO     , THOS    , TK      , TKT     ,      DIAG0570
      1           TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,      DIAG0580
      2           TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAB     ,      DIAG0590
      3           VBD     , VBDS    , VBM     , VBMSQ   , VB      , VBSD    ,      DIAG0600
      4           VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG    ,      DIAG0610
       COMMON     VIALB   , VIAL    , VIBG    , VILLB   , VIBL    , VIBM    ,      DIAG0620
      6           VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,      DIAG0630
      7           VL      , VLSQ    , VLS     , VS      , VSS     , WAIB    ,      DIAG0640
      8           WAS     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,      DIAG0650
      9           WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,      DIAG0660
       COMMON     WOM     , WOMS    , X       , X10     , X11     , XCLK    ,      DIAG0670
      1           XINT    , XP      , XS      , XX      , XXA     , YI      ,      DIAG0680
      2           YIS     , YO      , YOS     , ZZZ     , NSTMT                    DIAG0690
     DIMENSION PL(10)                                                              DIAG0700
      DIMENSION NDRAY(75)                                                          DIAG0710
     DIMENSION DATE(5),CASE(3),OID(8),XP(2,75),PL1(10),                            DIAG0720
     1      C(6),XP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAYDIAG0730
     21(100),DRAY(75),HT(18),DINT(8)                                              DIAG0740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                              DIAG0750
      IF(NSTMT-497)1,497,2                                                        DIAG0760
    1 CALL DUMPE                                                                  DIAG0770
    2 IF(NSTMT-529)1,529,1                                                        DIAG0780
  497 NSTM1=99999                                                                 DIAG0790
      IF(NDIAG-1)10,498,10                                                        DIAG0800
  498 DO 499 I=1,75                                                               DIAG0810
      DRAY(I)=99999.                                                              DIAG0820
  499 CONTINUE                                                                    DIAG0830
      LSW=0                                                                       DIAG0840
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      GO TO(501,502,503,504,505,506,507,508,509,510,511,512,513,514,     DIAG0850
     1      515,516,517,518,519,520,521,522,523,524,525,526,527,528,     DIAG0860
     2      529),LL                                                      DIAG0870
C                                                                        DIAG0880
C   DIAGNOSTIC OUTPUT.    ENTRY IS MADE TO SET CERTAIN                   DIAG0890
C     SETS OF OUTPUT VALUES INTO THE ARRAY DRAY DEPENDING               DIAG0900
C     ON THE VALUE OF LL, WHICH IS SET IN VARIOUS POINTS THROUGHOUT     DIAG0910
C     THE MAIN PROGRAM.                                                DIAG0920
C                                                                        DIAG0930
  529 DRAY(54)=REP                                                       DIAG0940
      NSTA=9999                                                          DIAG0950
      DRAY(45)=VILB                                                      DIAG0960
  528 DRAY(53)=Q                                                         DIAG0970
      DRAY(38)=ABAR                                                      DIAG0980
      DRAY(47)=RHOLB                                                     DIAG0990
  527 DRAY(46)=RHOGB                                                     DIAG1000
  526 DRAY(39)=TB                                                        DIAG1010
  525 DRAY(44)=EMLB                                                      DIAG1020
      DRAY(43)=EMGB                                                      DIAG1030
      DRAY(37)=RJ                                                        DIAG1040
  524 DRAY(42)=BETAB                                                     DIAG1050
      DRAY(41)=ALPHAB                                                    DIAG1060
      DRAY(50)=WGB                                                       DIAG1070
      DRAY(49)=WMGB                                                      DIAG1080
  523 DRAY(48)=WATB                                                      DIAG1090
  522 DRAY(52)=PBB                                                       DIAG1100
  521 DRAY(51)=PAB                                                       DIAG1110
  520 DRAY(70)=CFIM                                                      DIAG1120
      DRAY(69)=RDELIM                                                    DIAG1130
      DRAY(71)=TAIM                                                      DIAG1140
      DRAY(61)=CFOM                                                      DIAG1150
      DRAY(60)=RDELOM                                                    DIAG1160
      DRAY(36)=HM                                                        DIAG1170
      DRAY(35)=CD                                                        DIAG1180
  519 DRAY(34)=REM                                                       DIAG1190
  518 DRAY(64)=VBD                                                       DIAG1200
      DRAY(56)=WOM                                                       DIAG1210
      DRAY(59)=DELSO                                                     DIAG1220
      DRAY(58)=DELO                                                      DIAG1230
      DRAY(57)=THO                                                       DIAG1240
      DRAY(62)=TWOM                                                      DIAG1250
      DRAY(68)=DELSI                                                     DIAG1260
      DRAY(67)=DELI                                                      DIAG1270
      DRAY(66)=THI                                                       DIAG1280
      DRAY(65)=WIM                                                       DIAG1290
  517 DRAY(5)=A                                                          DIAG1300
      DRAY(12)=D                                                         DIAG1310
      DRAY(28)=SIG                                                       DIAG1320
  516 DRAY(14)=RA                                                        DIAG1330
      DRAY(9)=VL                                                         DIAG1340
      DRAY(4)=VG                                                         DIAG1350
  515 DRAY(1)=X                                                          DIAG1360
      DRAY(10)=CLM                                                       DIAG1370
      DRAY(29)=CGM                                                       DIAG1380
      DRAY(31)=VIGM                                                      DIAG1390
      DRAY(32)=VILM                                                      DIAG1400
      DRAY(33)=HKGM                                                      DIAG1410
      GO TO 1511                                                         DIAG1420
  514 DRAY(33)=HKGM                                                      DIAG1430
      DRAY(32)=VILM                                                      DIAG1440
  513 DRAY(31)=VIGM                                                      DIAG1450
      DRAY(29)=CGM                                                       DIAG1460
      DRAY(30)=CLM                                                       DIAG1470
  512 DRAY(63)=VBD                                                       DIAG1480
      DRAY(56)=WOM                                                       DIAG1490
      DRAY(59)=DELSO                                                     DIAG1500
      DRAY(58)=DELO                                                      DIAG1510
      DRAY(57)=THO                                                       DIAG1520
      DRAY(62)=TWOM                                                      DIAG1530
      DRAY(68)=DELSI                                                     DIAG1540
      DRAY(67)=DELI                                                      DIAG1550
      DRAY(66)=THI                                                       DIAG1560
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      DRAY(65)=WIM                                                      DIAG1570
      DRAY(5)=A                                                         DIAG1580
      DRAY(12)=D                                                        DIAG1590
      DRAY(28)=SIG                                                      DIAG1600
      DRAY(14)=PA                                                       DIAG1610
      DRAY(9)=VL                                                        DIAG1620
      DRAY(8)=VG                                                        DIAG1630
      DRAY(1)=X                                                         DIAG1640
 1511 DRAY(55)=YO                                                       DIAG1650
      DRAY(54)=YI                                                       DIAG1660
  511 DRAY(11)=S                                                        DIAG1670
      DRAY(4)=VB                                                        DIAG1680
      DRAY(10)=VS                                                       DIAG1690
      DRAY(5)=A                                                         DIAG1700
      DRAY(27)=HLB                                                      DIAG1710
  510 DRAY(26)=HLA                                                      DIAG1720
  509 DRAY(13)=RV                                                       DIAG1730
      DRAY(18)=EML                                                      DIAG1740
      DRAY(17)=EMG                                                      DIAG1750
      DRAY(20)=RHOL                                                     DIAG1760
  508 DRAY(19)=RHOG                                                     DIAG1770
      DRAY(3)=R                                                         DIAG1780
  507 DRAY(16)=BETA                                                     DIAG1790
      DRAY(15)=ALPHA                                                    DIAG1800
      DRAY(23)=WG                                                       DIAG1810
      DRAY(22)=WBG                                                      DIAG1820
  506 DRAY(21)=WAG                                                      DIAG1830
  505 DRAY(25)=PB                                                       DIAG1840
  504 DRAY(24)=PA                                                       DIAG1850
  503 DRAY(7)=TL                                                        DIAG1860
  502 DRAY(6)=TG                                                        DIAG1870
  501 DRAY(2)=P                                                         DIAG1880
      NDRAY(72)=NNA                                                     DIAG1890
      NDRAY(73)=NIS                                                     DIAG1900
      NDRAY(74) = NIB                                                   DIAG1910
      IF(NDIAG-1)540,550,540                                            DIAG1920
  540 WRITE (11) DRAY                                                   DIAG1930
      NNN=NNN+1                                                         DIAG1940
      DRAY(12)=0.0                                                      DIAG1950
C     WRITE(14)(DRAY(J),J=1,10)
      MM=MM+1                                                           DIAG1970
      GO TO 63                                                          DIAG1980
C                                                                       DIAG1990
C  DIAGNOSTIC OUTPUT - VARIABLES NOT YET COMPUTED THIS                  DIAG2000
C     ITERATION ARE SET TO 1085. PRINT OUT NINE LINES                   DIAG2010
C     OF OUTPUT.                                                        DIAG2020
C                                                                       DIAG2030
  550 WRITE (6,1001) (DRAY(I),I=1,9)                                    DIAG2040
  551 WRITE (6,1002) (DRAY(I),I=10,18)                                  DIAG2050
  552 WRITE (6,1003) (DRAY(I),I=19,27)                                  DIAG2060
  553 WRITE (6,1004) (DRAY(I),I=28,36)                                  DIAG2070
  554 WRITE (6,1005) (DRAY(I),I=29,45)                                  DIAG2080
  555 WRITE (6,1006) (DRAY(I),I=46,54)                                  DIAG2090
  556 WRITE (6,1007) (DRAY(I),I=55,63)                                  DIAG2100
  557 WRITE (6,1008) (DRAY(I),I=64,71)                                  DIAG2110
  558 CONTINUE                                                          DIAG2120
      WRITE (6,1009) NNA,NIS,NIB                                        DIAG2130
   10 NSTMT=10                                                          DIAG2140
      RETURN                                                            DIAG2150
   63 NSTMT=63                                                          DIAG2160
      RETURN                                                            DIAG2170
C                                                                       DIAG2180
C   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.                      DIAG2190
C                                                                       DIAG2200
 1001 FORMAT(1HO,13X,1HX,13X,1HD,13X,1HB,12X,2HV3,11X,1HA,12X,2HTG,12X,  DIAG2210
     12HTL,12X,2HVG,12X,2HVL,/,6X,9E14.4)                               DIAG2220
 1002 FORMAT(1HO,12X,2HV5,11X,1HS,11X,1HO,12X,2HRV,12X,2HPA,9X,         DIAG2230
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,9E14.4)                 DIAG2240
 1003 FORMAT(1HO,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,      DIAG2250
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,9E14.4)                  DIAG2260
 1004 FORMAT(1HO,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,10X,4HVIGM,10X,         DIAG2270
     14HVILM,11X,3HKGM,11X,3HREM,11X,3HCDM,12X,2HHM,/,6X,10E14.4)       DIAG2280
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 1005 FORMAT(1HO,12X,2HRB,12X,2HAB,12X,2HTB,11X,3HRVB,9X,5HALPHB,          DIAG2300
     19X,5HBETAB,11X,3HMGB,11X,3HMLB,10X,4HVILB,/,6X,9E14.4    )          DIAG2310
 1006 FORMAT(1HO,10X,4HROGB,10X,4HROLB,10X,4HWAGB,10X,4HWBGB,             DIAG2320
     111X,3HWGP,11X,3HPAB,11X,3HPBB,11X,1HQ,11X,3HREP,/,6X,9E14.4)        DIAG2330
 1007 FORMAT(1HO,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,      DIAG2340
     19X,5HREDOM,10X,4HCPOM,10X,4HTWOM,11X,3HVBD,/,6X,9E14.4)             DIAG2350
 1008 FORMAT(1HO,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*1,9X,   DIAG2360
     15HREDIM,10X,4HCPIM,10X,4HTWIM,/,6X,8E14.4)                          DIAG2370
 1009 FORMAT(1HO,10X,3HNNA,9X,3HNIS,9X,3HNIB,2X,3(6X,I6))                 DIAG2380
C1032 FORMAT(1H1,120X,5HPAGE,I3,//,1X,15HRBAR TWO-PHASE ,                 DIAG2390
C     1      26H TWO-COMPONENT NOZZLE FLOW,// )                           DIAG2400
       END                                                                DIAG2410
       SUBROUTINE WRITE      (DVGSQ,DTL,RHOLM,DVLSQ,DEMAG,DEMBG,         WRIT0010
      1      DELV2,EMG,HLA1,CAG1,DELT,HLB1,CBG1,SM,AM,BM,DX,DS)           WRIT0020
       WRITE (6,1231) DVGSQ,DTL,RHOLM,DVLSQ,DEMAG,DEMBG,                  WRIT0030
      1      DELV2,EMG,HLA1,CAG1,DELT,HLB1,CBG1,SM,AM,BM,DX,DS            WRIT0040
       RETURN                                                             WRIT0050
 9231 FORMAT(1HO,12X,5HDVGSQ,14X,3HDTL,12X,5HRHOLM,12X,5HDVLSQ,12X,       WRIT0060
     15HDEMAG,12X,5HDEMBG,12X,5HDELV2,/,1X,1P7E17.6,//,15X,3HEMG,14X,     WRIT0070
      1   3HLA1,13X,4HCAG1,13X,4HDELT,14X,3HLB1,13X,4HCBG1,                WRIT0080
      1      15X,2HSM,/,1X,7E17.6,//                                       WRIT0090
      2      16X,2HAM,15X,2HBM,15X,2HDX,15X,2HDS,/,1X,7E17.6)              WRIT0100
       END                                                                WRIT0110
       SUBROUTINE OUTPUT(N,LPG,MGBO)                                      OUTP0010
C SUBROUTINE TO READ SAVED PRINT LINES FROM LOGICAL                       OUTP0020
C     TAPE 20 AND PRINT THEM ON FORTARAN OUTPUT TAPE.                     OUTP0030
       DIMENSION DRAY(75),NDRAY(75)                                       OUTP0040
       EQUIVALENCE (DRAY(1),NDRAY(1))                                     OUTP0050
       REWIND 11                                                          OUTP0060
       L=1                                                                OUTP0070
    1  IF(N)99,99,2                                                       OUTP0080
    2  READ (11)DRAY                                                      OUTP0090
       IF(L)5,5,4                                                         OUTP0100
    4  WRITE (6,1032) LPG                                                 OUTP0110
       LPG=LPG+1                                                          OUTP0120
       L=0                                                                OUTP0130
       GO TO 6                                                            OUTP0140
    5  WRITE (6,998)                                                      OUTP0150
       L=1                                                                OUTP0160
    6  WRITE (6,1001) (DRAY(I),I=1,9)                                     OUTP0170
       WRITE (6,1002) (DRAY(I),I=10,18)                                   OUTP0180
       WRITE (6,1003) (DRAY(I),I=19,27)                                   OUTP0190
       WRITE (6,1004) (DRAY(I),I=28,36)                                   OUTP0200
       WRITE (6,1005) (DRAY(I),I=37,45)                                   OUTP0210
       WRITE (6,1006) (DRAY(I),I=46,54)                                   OUTP0220
       WRITE (6,1007) (DRAY(I),I=55,63)                                   OUTP0230
       IF(MGBO) 7,8,7                                                     OUTP0240
    7  WRITE (6,1008) (DRAY(I),I=64,71)                                   OUTP0250
    8  CONTINUE                                                           OUTP0260
       WRITE (6,1009) (NDRAY(I),I=72,74)                                  OUTP0270
       N=N-1                                                              OUTP0280
       GO TO 1                                                            OUTP0290
   99  REWIND 11                                                          OUTP0300
       RETURN                                                             OUTP0310
  998  FORMAT(1HO,///  )                                                  OUTP0320
C1000 FORMAT(6X,1P9E14.4)                                                 OUTP0330
 1001  FORMAT(1HO,13X,1HX,11X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,  OUTP0340
     12HTL,12X,2HVG,12X,2HVL,/,6X,9E14.4)                                 OUTP0350
 1002  FORMAT(1HO,12X,2HXS,13X,1HS,13X,1HD,12X,2HKV,12X,2HKA,9X,          OUTP0360
     15HALPHA,10X,4HBETA,12X,2HWL,12X,2HWT,/,6X,9E14.4)                   OUTP0370
 1003  FORMAT(1HO,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,       OUTP0380
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,9E14.4)                    OUTP0390
 1004  FORMAT(1HO,3X,5HSIGMA,11X,3HCOM,11X,3HCLM,10X,4HVIGM,10X,          OUTP0400
     14HVILM,11X,3HKGM,11X,3HRGM,11X,3HCPM,12X,3HMM,/,6X,9E14.4)
 1005  FORMAT(1HO,12X,2HRB,12X,2HAB,12X,2HTB,11X,3HRVB,9X,5HALPHB,        OUTP0420
     19X,5HBETAB,11X,3HMGB,11X,3HMLB,10X,4HVILB,/,6X,9E14.4)              OUTP0430
 1006  FORMAT(1HO,10X,4HROGB,10X,4HROLB,10X,4HWAGB,10X,4HWBGB,            OUTP0440
     111X,3HWGP,11X,3HPAB,11X,3HPBB,11X,1HQ,11X,3HREP,/,6X,9E14.4)        OUTP0450
 1007  FORMAT(1HO,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,      OUTP0460
     19X,5HREDOM,10X,4HCPOM,10X,4HTWOM,11X,3HVBD,/,6X,9E14.4)             OUTP0470
 1008  FORMAT(1HO,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*1,9X,   OUTP0480
     15HREDIM,10X,4HCPIM,10X,4HTWIM,/,6X,8E14.4)                          OUTP0490
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 1009 FORMAT(1H0,10X,3HNNA,9X,3HNIS,9X,3HNIB           /,2X,
     1     3(6X,I6))
 1032 FORMAT(1H1,120X,5HPAGE ,I3,//,1X,15HREAL TWO-PHASE ,
     1     26H TWO-COMPONENT NOZZLE FLOW,// )
      END
      SUBROUTINE XPTBL(XP)
C  SUBROUTINE TO PRINT OUT XP TABLE C
      DIMENSION XP(2,75)
  792 L1=1
      L2=8
  794 WRITE (6,793)
C  PRINT OUT NEW X(P) TABLE
  795 WRITE (6,909) (XP(1,MT),MT=L1,L2)
      WRITE (6,917) (XP(2,MT),MT=L1,L2)
      IF (L2-72) 796,797,798
  796 L1=L1+8
      L2=L2+8
      GO TO 795
  797 L1=L1+8
      L2=L2+3
      GO TO 795
  798 RETURN
  793 FORMAT(1H1,//,50X,14HNEW X(P) TABLE,///)
  909 FORMAT(1H0,3X,5HPRESS,1X,10(2X,F5.4))
  917 FORMAT(1H ,7X,1HX,1X,10(2X,F5.4))
      END
      SUBROUTINE TABLE
C    GENERATE NOZZLE FLOW TABLE TAPE SUBROUTINE
C
C
      DIMENSION TVAR(14,2,50),C(6),XVAR(4,35),TSAV1(35,4,35),
     1     TSAV2(35,4,35)
      COMMON TSAV1,TSAV2
      DO 1 I=1,14
      DO 1 J=1,2
      DO 1 K=1,50
      TVAR(I,J,K)=1.0E5
    1 CONTINUE
      DO 2 L=1,35
      DO 2 I=1,4
      DO 2 K=1,35
      TSAV1(L,I,K) = 100000.
      TSAV2(L,I,K) = 100000.
    2 CONTINUE
      DO 25 I = 1,4
      DO 25 J=1,35
C     THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENSIO
      XVAR (I,J) = 100000.
   25 CONTINUE
    3 L=1
      I=1
      K=1
      ICARD=0
    4 READ (5,901) (C(M),M=1,6)
      ICARD=ICARD+1
      IF (C(1))5,6,5
    6 IF(C(2)-1.0) 11,11,5
    5 DO 10 M = 1,5,2
      IF(C(M)+C(M+1) - 199999.)8,13,13
    8 TSAV1(L,I,K) = C(M)
      TSAV2(L,I,K) = C(M+1)
      IF(K-35) 9,9,26
    9 K = K+1
   10 CONTINUE
      GO TO 4
   26 WRITE (6,900) I,L,K
      GO TO 37
   11 XV = C(2)
      XVAR(I,L) = C(1)
      GO TO 4
   13 IF(XV) 15,14,15
   14 L = L+1
```

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      K=1                                                               TABL0470
      IF(L-35)4,4,27                                                    TABL0480
C     THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENSIOTABL0490
   15 IF(I-4)16,17,17                                                   TABL0500
   16 L=1                                                               TABL0510
      I = I + 1                                                         TABL0520
      K=1                                                               TABL0530
      GO TO 4                                                           TABL0540
   27 WRITE (6,927) I                                                   TABL0550
      GO TO 37                                                          TABL0560
   17 CONTINUE                                                          TABL0570
      REWIND 12
      WRITE (12) XVAR                                                   TABL0580
      WRITE (12) ISAV1                                                  TABL0590
      WRITE (12) ISAV2                                                  TABL0600
C  NEXT CARD IS FIRST CARD OF TVAR ARRAY                                TABL0610
      DO 38 I=1,14                                                      TABL0620
      K=1                                                               TABL0630
   29 READ (5,901) (C(L),L=1,6)                                         TABL0640
      ICARD=ICARD+1                                                     TABL0650
      DO 34 L=1,5,2                                                     TABL0660
      IF(C(L)+C(L+1)-199999.)32,30,30                                   TABL0670
   30 TVAR(I,1,K)=100000.                                               TABL0680
      TVAR(I,2,K)=100000.                                               TABL0690
      GO TO 33                                                          TABL0700
   32 TVAR(I,1,K)=C(L)                                                  TABL0710
      TVAR(I,2,K)=C(L+1)                                                TABL0720
      IF(K-51)33,37,37                                                  TABL0730
   33 K=K+1                                                             TABL0740
   34 CONTINUE                                                          TABL0750
      GO TO 29                                                          TABL0760
   38 CONTINUE                                                          TABL0770
   36 WRITE (12) TVAR                                                   TABL0780
      CSAVE=0.0                                                         TABL0790
      READ (5,901) (C(L),L=1,6)                                         TABL0800
      ICARD=ICARD+1                                                     TABL0810
      DO 1036 I=1,6                                                     TABL0820
 1036 CSAVE = CSAVE + C(I)                                              TABL0830
      IF(CSAVE)37,1037,37                                               TABL0840
   37 CALL INTERP(V,20,1.0,P)                                           TABL0850
      CALL DUMP                                                         TABL0860
      CALL EXIT                                                         TABL0870
 1037 CONTINUE
      ENDFILE12
      REWIND 12
      RETURN                                                            TABL0900
  900 FORMAT(1H0,7X,19HERROR IN INPUT DATA,3I6)                         TABL0910
  901 FORMAT (6E12.6)                                                   TABL0920
  927 FORMAT(1H0,7X,36HEXCEDING MAXIMUM TEMPERATURE INPUT ,             TABL0930
     1 7HERE N =,I3)                                                    TABL0940
      END                                                               TABL0950
      SUBROUTINE INTERP(VAR,N,T,P)                                      INTR0010
C                                                                       INTR0020
C   IF N=0, READ IN ALL TABLES, SET UP T ARRAY, AND EXIT.               INTR0030
C   IF N= 20 WRITE OUT ALL TABLES AND EXIT.                             INTR0050
C   IF N=1 THRU 4, GET APPROPRIATE TABLES FROM TAPE,                    INTR0060
C     INTERPOLATE FOR VALUE OF VAR AND EXIT.                            INTR0070
C   IF N=5 THRU 13, INTERPOLATE FOR VALUE OF VAR AND EXIT.              INTR0080
C                                                                       INTR0090
      DIMENSION TVAR(14,2,50),TVAR1(35,4,35),TVAR2(35,4,35)             INTR0100
     1         ,TRAY(4,35),H(14)                                        INTR0110
      COMMON IVAR1,TVAR2,TVAR                                           INTR0120
      IBM=0                                                             INTR0130
      IF(N) 1, 1,10                                                     INTR0140
    1 K=1                                                               INTR0150
      REWIND 12
      READ (12) TRAY                                                    INTR0160
      READ (12) TVAR1                                                   INTR0170
      READ (12) TVAR2                                                   INTR0180
C                                                                       INTR0190
C   T ARRAY HAS BEEN SET UP, NO. OF T RECORDS (K) IS SET, NOW           INTR0200
C         PROCEED TO BRING IN PERMANENT ARRAYS.                         INTR0210
```

```
C                                                                       INTR0220
      READ (12) TVAR                                                    INTR0230
      RETURN                                                            INTR0250
   10 IF(N-20) 100,12,11                                                INTR0260
   11 WRITE (6,911)                                                     INTR0270
      CALL EXIT                                                         INTR0280
C  WRITE OUT TABLES FOR N=20, T IS PAGE COUNT.                          INTR0290
   12 CALL ADATA                                                        INTR0440
      LCT1=0                                                            INTR0450
      LPGCT=T                                                           INTR0460
      WRITE (6,920) LPGCT                                               INTR0470
      DO 30 L=1,14                                                      INTR0480
   13 NT=1                                                              INTR0490
   14 TEST1=TVAR(L,1,NT)+TVAR(L,2,NT)                                   INTR0500
      IF(TEST1-2.0+99999.)15,15,16                                      INTR0510
   15 NT=NT+1                                                           INTR0520
      IF(NT-50)14,14,1000                                               INTR0540
   16 TVAR(L,1,NT)=0.0                                                  INTR0550
      TVAR(L,2,NT)=0.0                                                  INTR0560
      IF(NT-1)515,520,515                                               INTR0570
C  NOW INPUT THIS TABLE                                                 INTR0580
  520 WRITE (6,9520) H(L)                                               INTR0590
      LCT1 = LCT1+4                                                     INTR0600
      GO TO 530                                                         INTR0610
  515 NT=NT-1                                                           INTR0620
      WRITE (6,916) H(L)                                                INTR0630
      L1=1                                                              INTR0640
      L2=AMINO(8,NT)                                                    INTR0650
      LT=1                                                              INTR0660
   18 WRITE (6,918) H(L),(TVAR(L,2,LK),LK=L1,L2)                        INTR0670
      WRITE (6,919) (TVAR(L,1,LK),LK=L1,L2)                             INTR0680
      IF(L2-NT)19,20,20                                                 INTR0690
   19 L1=L1+8                                                           INTR0700
      L2=AMINO(L2+8,NT)                                                 INTR0710
      LT=LT+1                                                           INTR0720
      GO TO 18                                                          INTR0730
   20 LCT1=LT*3+3+LCT1                                                  INTR0740
  530 IF(LCT1-52)30,21,21                                               INTR0750
   21 WRITE (6,922) LPGCT                                               INTR0760
      LPGCT=LPGCT+1                                                     INTR0770
      LCT1=1                                                            INTR0780
   30 CONTINUE                                                          INTR0790
      REWIND 12                                                         INTR0800
      DATA H(1)/4H CAG/                                                 INTR0810
      DATA H(2)/4H CBG/                                                 INTR0820
      DATA H(3)/4H WAG/                                                 INTR0830
      DATA H(4)/4H WBG/                                                 INTR0840
      DO 50 L=1,4                                                       INTR0850
      IF (TRAY (L,1)-99999.) 29,29,50                                   INTR0860
   29 WRITE (6,920) LPGCT                                               INTR0870
   31 WRITE (6,916) H(L)                                                INTR0880
      LPGCT=LPGCT+1                                                     INTR0890
      LCT1=1                                                            INTR0900
      DO 45 KK=1,35                                                     INTR0910
      IF (TRAY (L,KK)-99999.) 32,32,45                                  INTR0920
   32 WRITE (6,934) TRAY(L,KK)                                          INTR0930
      LCT1=LCT1+1                                                       INTR0940
      NCT=1                                                             INTR0950
   34 TEST1=TVAR1(KK,L,NCT)+TVAR2(KK,L,NCT)                             INTR0960
      IF(TEST1-2.0+99999.)35,36,36                                      INTR0970
   35 NCT=NCT+1                                                         INTR0980
      IF(NCT-35)34,34,1000                                              INTR0990
   36 NCT=NCT-1                                                         INTR1000
      L1=1                                                              INTR1010
      L2=AMINO(8,NCT)                                                   INTR1020
   37 CONTINUE                                                          INTR1030
   38 DO 63 LT=L1,L2                                                    INTR1040
      IF(TVAR2(KK,L,LT)-100000.)63,60,63                                INTR1050
   60 TVAR1(KK,L,LT)=0.0                                                INTR1060
      TVAR2(KK,L,LT)=0.0                                                INTR1070
   63 CONTINUE                                                          INTR1080
```

```
FILE: TH3      FORTRAN A1  NAVAL POSTGRADUATE SCHOOL

      WRITE (6,938) H(L),(TVAR2(KK,L,LT),LT=L1,L2)                      INTR1080
   39 WRITE (6,939) (TVAR1(KK,L,LT),LT=L1,L2)                           INTR1090
      LCT1=LCT1+3                                                       INTR1100
      IF(LCT1-52)66,65,65                                               INTR1110
   65 WRITE (6,920) LPGCT                                               INTR1120
      LPGCT=LPGCT+1                                                     INTR1130
      LCT1=3                                                            INTR1140
   66 IF(L2-NCT)40,41,41                                                INTR1150
   40 L1=L1+8                                                           INTR1160
      L2=AMIN0(L2+8,NCT)                                                INTR1170
      GO TO 38                                                          INTR1180
   41 IF(LCT1-52)45,42,42                                               INTR1190
   42 WRITE (6,920) LPGCT                                               INTR1200
      LPGCT=LPGCT+1                                                     INTR1210
      LCT1=3                                                            INTR1220
   45 CONTINUE                                                          INTR1230
   50 CONTINUE                                                          INTR1240
      IF(IBW-1)1047,1046,1047                                           INTR1250
 1046 N=0                                                               INTR1260
 1047 RETURN                                                            INTR1270
C   N=1 THRU 18 - INTERPOLATE ROUTINE                                   INTR1280
  100 IF(N-4)101,101,150                                                INTR1290
  101 DO 104 I=1,35                                                     INTR1300
      IF(TRAY(N,I)-T)104,105,105                                        INTR1310
  104 CONTINUE                                                          INTR1320
      GO TO 120                                                         INTR1330
  105 IF(I-1)106,120,106                                                INTR1340
  106 IM1=I-1                                                           INTR1350
      TK=TRAY(N,I)                                                      INTR1360
      TK1=TRAY(N,IM1)                                                   INTR1370
      DO 107 J1=1,35                                                    INTR1380
      IF(TVAR1(IM1,N,J1)-P)107,107,108                                  INTR1390
  107 CONTINUE                                                          INTR1400
      GO TO 120                                                         INTR1410
  108 IF(J1-1)109,120,109                                               INTR1420
  109 IF(TVAR1(IM1,N,J1)+TVAR2(IM1,N,J1)-2.0*99999.)110,120,120         INTR1430
  110 JM1=J1-1                                                          INTR1440
      DIFFT=TVAR1(IM1,N,J1)-TVAR1(IM1,N,JM1)                            INTR1450
      DIFF1=      TVAR1(IM1,N,J1)-P                                     INTR1460
      PC1=-(DIFF1/DIFFT)*(TVAR2(IM1,N,J1)-TVAR2(IM1,N,JM1))+            INTR1470
     1TVAR2(IM1,N,J1)                                                   INTR1480
      DO 111 J2=1,35                                                    INTR1490
      IF(TVAR1(I,N,J2)-P)111,111,112                                    INTR1500
  111 CONTINUE                                                          INTR1510
      GO TO 120                                                         INTR1520
  112 IF(J2-1)113,120,113                                               INTR1530
  113 JM2=J2-1                                                          INTR1540
      IF(TVAR1(I,N,J2)+TVAR2(I,N,J2)-2.*99999.)114,120,120             INTR1550
  114 DIFFT=TVAR1(I,N,J2)-TVAR1(I,N,JM2)                                INTR1560
      DIFF1=      TVAR1(I,N,J2)-P                                       INTR1570
      PC2=-(DIFF1/DIFFT)*(TVAR2(I,N,J2)-TVAR2(I,N,JM2))+TVAR2(I,N,J2)   INTR1580
      VAR=(P-TK1)/(TK-TK1)*(PC2-PC1)+PC1                                INTR1590
  130 RETURN                                                            INTR1600
  120 N=0                                                               INTR1610
      IBW=1                                                             INTR1620
      GO TO 12                                                          INTR1630
  150 N=N-4                                                             INTR1640
      IF(N-15)155,1000,1000                                             INTR1650
  155 CONTINUE                                                          INTR1660
      DO 151 I=1,50                                                     INTR1670
      IP=I                                                              INTR1680
      IF(TVAR(N,1,I)-T)151,151,152                                      INTR1690
  151 CONTINUE                                                          INTR1700
      GO TO 120                                                         INTR1710
  152 IF(TVAR(N,1,I)+TVAR(N,2,I)-2.0*99999.)153,120,120                 INTR1720
  153 IF(IP-1)154,120,154                                               INTR1730
  154 IP1=IP-1                                                          INTR1740
      VAR=((T-TVAR(N,1,IP1))/(TVAR(N,1,IP)-TVAR(N,1,IP1)))             INTR1750
     1*(TVAR(N,2,IP)-TVAR(N,2,IP1))+TVAR(N,2,IP1)                       INTR1760
      GO TO 130                                                         INTR1770
 1000 CONTINUE                                                          INTR1780
      CALL OUTPUT                                                       INTR1790
```

```
      CALL DUMP                                                          INTR1890
      RETURN                                                             INTR1810
  911 FORMAT(1HO,7X,33HILLEGAL CALLING SEQUENCE TO INTRP)                INTR1820
  916 FORMAT(1HO,56X,11HINPUT TABLE,2X,A5,/)                             INTR1830
  918 FORMAT(1HO,A6,1P8E15.6)                                            INTR1840
  919 FORMAT (1H ,2X,4HTEMP,1P8E15.6      )                              INTR1850
  920 FORMAT(1H1,/,120X,4HPAGE,2X,I3)                                    INTR1860
  934 FORMAT(1HO,40X,14HTEMPERATURE = ,F12.4,//)                         INTR1870
  938 FORMAT(1HO,3X,A6,12HE15.6)                                         INTR1880
  939 FORMAT(1H ,3X,5HPRESS ,1X, 1P8E15.6)                               INTR1890
 9520 FORMAT(1HO,/,1HO,7X,18HNO INPUT FOR TABLE, A6)                     INTR1900
      END                                                                INTR1910
C*****************************************************************
      SUBROUTINE DUMP
      CALLEXIT
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE ADATA
      DIMENSION HT(18),H(14),HT1(18),H1(14)
      COMMON HT,H
      DATA HT1/4H CAG,4H CBG,4H ZAG,4H ZAG,4H CAL,
     1         4H CBL,4H  LA,4H  LB,4H PBO,4HROAL,
     2         4HROBL,4H KAG,4H KBG,4HVIAL,4HVIBL,
     3         4HVIAG,4HVIBG,4H SIG/
      DATA H1/4H CAL,4H CBL,4H HLA,4H HLB,4H PBO,
     1        4HROAL,4HPOBL,4H KAG,4H KBG,4HVIAL,
     2        4HVIBL,4HVIAG,4HVIBG,4H SIG/
      DO 10 I=1,18
         HT(I)=HT1(I)
   10 CONTINUE
      DO 20 I=1,14
         H(I)=H1(I)
   20 CONTINUE
      RETURN
      END
```

LIST OF REFERENCES

1. National Aeronautics and Space Administration, Technical Report 32-987, Acceleration of Liquids in Two-Phase Nozzles by D. G. Elliott and E. Weinberg, July 1968.

2. AIAA/SAE/ASME 17th Joint Propulsion Conference, Report AIAA-81-1604, Biphase Turbine for Marine Propulsion by L. Hays, July 1981.

3. Tables of Thermal Properties of Gases, National Bureau of Standards Circular 564, November 1, 1955.

4. Flow Measurement/Instruments and Apparatus, Part 5 - Measurement of Quantity of Materials, The American Society of Mechanical Engineers, February 1959.

BIBLIOGRAPHY

Berstein, A., Heiser, W. H. and Hevenor, C., Compound-Compressible Nozzle Flow, Journal of Applied Mechanics Paper No. 67-APM-L, November 1966.

Cerini, D. J., A Two-Phase Rotary Separator Demonstration System for Geothermal Energy Conversion, 12th IECEC Paper No. 770135.

Cerini, D. J. and Hays, L. G., Power Production from Geothermal Brine with the Rotary Separator Turbine, American Institute of Aeronautics and Astronautics, Inc. Paper No. 809156, 1980.

Colwell, G. T., Low Density Nozzle Flow, The American Society of Mechanical Engineers Paper No. 68-WA/FE-9, August 1968.

Dash, S. M. and Thorpe, R. D., Shock-Capturing Model for One- and Two-Phase Supersonic Exhaust Flow, American Institute of Aeronautics and Astronautics Paper No. 80-1254, February 1981.

Ganic, E. M. and Rohsenow, W. M., On the Mechanism of Liquid Drop Deposition in Two-Phase Flow, The American Society of Mechanical Engineers Paper No. 76-WA/HT-18, July 1976.

Hays, L. and Neal, J., Biphase Turbines for Diesel Bottoming, Energy Research and Development Administration Paper No. 779077.

Hiley, P. E. and Wallace, H. W. and Booz, E. E., Nonaxisymmetric Nozzles Installed in Advanced Fighter Aircraft, AIAA/SAE 11th Propulsion Conference Paper No. 75-1316, August 1973.

Keenan, J. H. and Kaye, J., Gas Tables, John Wiley & Sons, Inc., 1948.

Lewis, W. G. E., Propelling Nozzle Research, lecture given to the Society on April 23, 1963.

Li, W. and Lam, S., Principles of Fluid Mechanics, Addison-Wesley Publishing Co., 1964.

Muench, R. K. and Ford, A. E., A Water-Augmented Air Jet for the Propulsion of High-Speed Marine Vehicles, paper presented at the AIAA 2nd Advanced Marine Vehicles and Propulsion Meeting, Seattle, Wash., May 1969.

Nunn, R. H. and Brandt, H., Aerodynamic Throttling of Two-Dimensional Nozzle Flows, August 1970.

Replogle, J. A., Myers, L. E. and Brust, K., Flow Measurements with Fluorescent Tracers, March 1968.

Schlichting, H., Boundary-Layer Theory, McGraw Hill Book Co., 1979.

Shapiro, A. E., The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. 1, The Ronald Press Co., 1953.

Streeter, V. L. and Wylie, E. B., Fluid Mechanics, Seventh Ed., McGraw-Hill Book Co., 1979.

Thornock, R. L. and Brown, E. F., An Experimental Study of Compressible Flow through Convergent-Conical Nozzles, Including a Comparison with Theoretical Results, ASME Publication Paper No. 71-WA/FE-3, June 1971.

Wagner, J. L., A Cold Flow Field Experimental Study Associated with a Two-Dimensional Multiple Nozzle, 1971.

Wagner, W. B. and Owczarek, J. A., An Investigation of the Corner Secondary Flows Generated in Planar Nozzles, The American Society of Mechanical Engineers Paper No. 73-WA/Fles-5, August 1973.

The American Society of Mechanical Engineers Paper No. 80-GT-90, Some Effects of Using Water as a Test Fluid in Fuel Nozzle Spray Analysis, December 1979.

Air Force Systems Command Report SRD-73-161, Techniques for Injection and Acceleration of Particles by Ultra High Speed Gas Jets, February 1974.

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